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DESIGN STUDIES AND MODEL TESTS OF THE STOWED TILT ROTOR CONCEPT

Volume III. Appendixes

Bernard L. Fry

The Boeing Company, Vertol Division

TECHNICAL REPORT AFFDL-TR-71-62

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13 ABSTRACT

The stowed-tilt-rotor stoppable rotor concept offers great potential for three missions requiring 2 combinations of relatively low downwash characteristics, good hover efficiency, and relatively high cruise speed and efficiency. These missions are 1) high-speed long-range rescue, 2) capsule recovery, and 3) VTOL medium transport. The present study will provide information on design criteria including the size and configuration of aircraft required to fulfill each of the three missions. The current study indicates that there is reasonable compatibility between the rescue and capsule recovery aircraft because their speed capabilities and required useful loads are similar. However, a much larger aircraft is required to accommodate all three missions. (A reduction in cargo box size for the transport mission can however provide a single compromise airframe size.) Consequently, a baseline configuration has been selected with a common lift/propulsion system combined with different fuselages for rescue aircraft and medium transport aircraft. The compromise made in the transport fuselage box size still provides a capacity in excess of most current medium transports, both helicopter and fixed-wing. The preliminary component design studies have generally confirmed the practicality of the concept and have not revealed any serious problem areas.

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NOTICE

14 KEY WORDS	LINK A		LINK B		LINK C	
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FOLDING ROTOR						
CONVERTIBLE ENGINES						
VTOL						
TILT ROTOR						
COMPOSITE AIRCRAFT						
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DESIGN STUDIES AND MODEL TESTS OF THE STOWED TILT ROTOR CONCEPT

Volume III. Appendixes

Bernard L. Fry

FOREWORD

This report was prepared by The Boeing Company, Vertol Division, Philadelphia, Pennsylvania, for the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, under Phase I of Contract F33615-69-C-1577. The contract objective is to develop design criteria and aerodynamic prediction techniques for the folding tilt rotor concept through a program of design studies, model testing and analysis.

The contract was administered by the Air Force Flight Dynamics Laboratory with Mr. Daniel E. Fraga (FV) as Project Engineer.

The reports published under this contract for Design Studies and Model Tests of the Stowed Tilt Rotor Concept are:

Volume I	Parametric Design Studies
Volume II	Component Design Studies
Volume III	Performance Data for Parametric Study Aircraft
Volume IV	Wind Tunnel Test of the Conversion Process of a Folding Tilt Rotor Aircraft Using a Semi-Span Unpowered Model
Volume V	Wind Tunnel Test of a Powered Tilt Rotor Performance Model
Volume VI	Wind Tunnel Test of a Powered Tilt Rotor Dynamic Model on a Simulated Free Flight Suspension System
Volume VII	Wind Tunnel Test of the Dynamics and Aerodynamics of Rotor Spinup, Stopping and Folding on a Semi-Span Folding Tilt Rotor Model
Volume VIII	Summary of Structural Design Criteria and Aerodynamic Prediction Techniques

This report has been reviewed and is approved.

Ernest J. Cross Jr.

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Lt. Colonel, USAF
Chief, V/STOL Technology Division

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APPENDIX I

DRAG AND DETAIL PERFORMANCE DATA FOR DESIGN POINT AIRCRAFT

This Appendix contains a description of the drag prediction methodology used in this study, minimum parasite drag breakdowns for all the point design aircraft, and detailed performance data for the Design Point I, II, and III aircraft.

1. DRAG METHODOLOGY

The Boeing method of drag buildup (as detailed in D8-2194-1, Drag Estimation of V/STOL Aircraft, E.A. Gabriel, 5 May 1969) was used in this study to obtain the zero lift drag of the aircraft. The drag coefficient is defined as:

$$C_D = C_{D_{P_{MIN}}} + \Delta C_{D_P} + C_{D_I} + \Delta C_{D_M} \qquad (16)$$

where

$C_{D_{P_{MIN}}}$ = minimum parasite drag

ΔC_{D_P} = parasite drag increase with lift

C_{D_I} = induced drag

(Drag due to lift: ΔC_{D_P} and C_{D_I})

ΔC_{D_M} = drag due to compressibility

In cruise flight the total drag is due primarily to the $C_{D_{P_{MIN}}}$, since the drag due to lift is small at cruise lift coefficients, and the drag due to compressibility is generally greatly reduced by prudent selection of aircraft geometry. The total parasite drag of each aircraft component is accounted for by the buildup of skin friction, three-dimensional effects, interference, and pressure drag due to flow separation. The results of these calculations are summed up and reduced to coefficient form, $C_{D_{P_{MIN}}}$, to which is added the drag due to lift ($\Delta C_{D_P} + C_{D_I}$). As cruise speed increases the effects of compressibility must be accounted for, beginning at the critical Mach number. Above that speed boundary layer separation is caused by shock waves, which results in a rapid drag rise. This

effect on drag coefficient is provided for in the drag equation by the ΔC_{D_M} term.

2. DRAG BUILDUP METHOD

For the purpose of summing all of the parasite drag forces, the concept of "equivalent parasite area" conveniently refers each drag force to the dynamic pressure:

$$f_e = D/q \tag{17}$$

since: $$C_D = \frac{D}{qS} = f_e/S \text{ then } f_e = C_D S \tag{18}$$

The minimum parasite drag is calculated, in f_e form, for each component (wing, fuselage, etc.), then summed and nondimensionalized by the gross wing area to find the total minimum parasite drag:

$$C_{D_{P_{MIN}}} = \frac{\Sigma f_e}{S_w} \tag{19}$$

$$= \left[f_{e_{fus}} + f_{e_{wing}} + f_{e_{tail}} + f_{e_{nac}} + ----\right]\left(\frac{1}{S_w}\right) \tag{20}$$

The general scheme of the process for calculating the minimum parasite drag of each component is shown in Figure 131 and is discussed in the following paragraphs.

(a) Flight Conditions

The mission requirements establish the aircraft geometry and flight conditions (velocity and altitude).

(b) Skin Friction

Knowing the component dimensions and flight conditions, the skin friction drag can be readily calculated from the skin friction laws for a flat plate. This is done for a fully turbulent boundary layer and includes any drag due to distributed roughness (related to type of surface finish).

(c) Three-Dimensional Effects

These are due to the displacement effects of a body* with finite thickness (sometimes called form drag). 3-D effects consist primarily of increased skin friction due to the increased local flow velocity (caused by body displacement of the fluid) and of pressure drag. Both of these effects are accounted for as an increase of skin friction by data correlations related to body geometry.

(d) Discrete Roughness

This is an additional skin friction increase to account for rivets and seams.

(e) Basic Drag

The basic drag consists of items (b), (c), and (d) and represents the drag of the body in isolated or free flow.

(f) Interference

This drag is due to the influence of one component upon another. Parasitic interference is generally due to increased pressure drag and boundary layer losses occurring at the intersection of components.

(g) Excrescences

This drag is caused by small holes, and protuberances such as antennae, windows, vents, access doors, cowl fasteners, etc. Also, this drag is accounted for by a percentage increase of the basic drag.

(h) Component Drag

This is defined as the basic drag plus interference, excrescence drag and any additional items such as canopy, afterbody pressure drag, inlets, control surface gaps, etc.

*Body is a general term here that could be any component such as wing, fuselage, or nacelle, etc.

The results of the drag calculation are best summarized and presented on a drag breakdown sheet as illustrated in Table XXXIX. This format is most useful for summing the component drags, comparing drag breakdowns of different configurations, identifying areas of excessive drag and checking for errors.

The parasite drag variation with lift, ΔC_{D_P}, includes:

- o Any additional induced drag due to non-elliptic loading and due to longitudinal trim
- o Skin friction, pressure drag and interference drag increased due to increasing angle of attack

The ΔC_{D_P} variation is best determined from wind tunnel and flight test data. This data is not usually available in the preliminary design stage, however, in its absence the Oswald airplane efficiency factor (e) is used. It has been found that ΔC_{D_P} increases approximately proportional to C_L^2 (until excessive flow separation occurs at high angles of attack) and can therefore be represented as an increased induced drag. The total drag due to lift is then:

$$C_{D_i} + \Delta C_{D_P} = \frac{C_L^2}{\pi ARe} \qquad (21)$$

where the value of e is always less than unity. For preliminary design estimates, e = .80 should be attainable for a typical high-wing V/STOL cargo aircraft with good afterbody design and good fillets at the wing-fuselage and wing-nacelle intersection. Methods of estimating airplane efficiency factor are reviewed in Reference AII.1, Section 5.2.3, including corrections for aspect ratio, sweep, taper and thickness of the wing and for the Reynolds Number and Mach number.

At airspeeds up to roughly M = 0.5, air can be considered to be an incompressible fluid, and compressibility effects will generally be negligible at cruise lift coefficients. At some higher speed the local velocity at some point on the wing reaches the speed of sound. The critical Mach number, M_{CR}, is that theoretical dividing line between the incompressible and the compressible flight regimes. However, the critical Mach number may be exceeded substantially before the drag rises significantly. The Boeing Commercial Airplane Division (CAD) has

established the definition of the Drag Divergence Mach Number, M_{DD}, as the freestream Mach number where the drag coefficient has risen 20 counts from the incompressible level ($\Delta C_{D_M} = 0.0020$). It does not necessarily define the most economical cruise speed for a turboprop aircraft but has been used here for analysis of all V/STOL aircraft regardless of means of propulsion. Compressibility drag rise trends and corrections for camber, aspect ratio and thickness are obtained from D8-2194-1, previously cited.

3. DRAG BREAKDOWNS

Minimum parasite drag breakdowns of the Design Point I, II, III, IV, and V aircraft obtained with the method outlined in Section 1.1 are presented as Tables XL through XLVI. They were evaluated at the following flight conditions (for Air Force Hot Day temperature):

Design Point	Cruise Speed (kn tas)	Cruise Altitude (ft)
I	400	25,000
II	400	20,000
III (Rescue Aircraft)	400	20,000
IV	300	20,000
V (Rescue Aircraft)	300	20,000
V (Capsule Recovery Aircraft)	400	20,000
V (Transport Aircraft)	300	20,000

4. PERFORMANCE DATA

Detail performance data are presented in Figures 132 through 229 for the three basic design point aircraft. Figures 132 through 155 refer to Design Point I, 156 through 204 to Design Point II, and 205 through 229 to Design Point IV.

TABLE XXXIX. MINIMUM PARASITE DRAG BREAKDOWN CONFIGURATION

Component	Wetted Area	C_f*	Increment %	Δf_e	f_e (ft^2)
Fuselage					
3-Dimensional Effects					
Excrescences					
Canopy					
Afterbody (Base Drag)					
Wing					
3-D Effects					
Excrescences					
Gaps (flaps, slats, ailerons, spoliers)					
Body Interference					
Horizontal Tail					
3-D Effects					
Excrescences & gaps					
Interference					
Vertical Tail					
3-D Effects					
Excrescences & gaps					
Interference					
Rotor Nacelles					
3-D Effects per nacelle					
Excrescences					
Interference					TOTAL
Blades Folded					
Engine - Nacelles					
Effects of Boattail					
Excrescences per nacelle					TOTAL
Interference					
Inlets					
Landing Gear Pod					
3-D Effects					
Excrescences					
Interference					
Miscellaneous					
Roughness (% $\Sigma C_f A_{WET}$)					
Cooling					
Trim					
Air Conditioning					
Totals (ft^2)					

TABLE XL. MINIMUM PARASITE DRAG BREAKDOWN FOR DESIGN POINT I RESCUE AIRCRAFT

Component	Wetted Area	C_f*	Increment f_e % Δf_e	(ft^2)
Fuselage	1201.4	0.001950	2.5185	
3-Dimensional Effects			0.2132	
Excrescences			0.2027	
Canopy			0.1156	
Afterbody (Base Drag)			0.3012	
Turrets (Faired for Cruise)				0
				3.3512
Wing	1245.3	0.002439	3.0373	
3-D Effects			1.0141	
Excrescences			0.1705	
Gaps (flaps, slats ailerons, spoilers)			0.3276	
Body Interference			0.9492	
				5.4987
Horizontal Tail	375.3	0.002659	0.9979	
3-D Effects			0.3048	
Excrescences and gaps			0.1163	
Interference			0.5582	
				1.9772
Vertical Tail	310.3	0.002459	0.7630	
3-D Effects			0.2128	
Excrescences and gaps			0.0872	
Interference			0.0353	
				1.0983
Rotor Nacelles	390.3	0.002111	0.8239	
3-D Effects (per nacelle)			0.0694	
Excrescences			0.1902	
Interference			0.1291	
Blades Folded			0.2520	TOTAL
				2.9292
Engine Nacelles	241.6	0.002353	0.5685	
Effects of Boattail (per nacelle)			0.0476	
Excrescences			0.2294	
Interference			0.4794	
Inlets			0.4914	TOTAL
				3.6326
Landing Gear Pod				
3-D Effects				
Excrescences				
Interference				
Miscellaneous				
Roughness (% $\Sigma C_f A_{WET}$)		*R_e/f = 1.9291×10^6	0.6597	
Cooling			0.4472	
Trim			0.0652	
Air Conditioning				
				1.1721
TOTALS (ft^2)	4396.1	0.002298		19.695

TABLE XLI. MINIMUM PARASITE DRAG BREAKDOWN FOR DESIGN POINT II CAPSULE RECOVERY AIRCRAFT

Component	Wetted Area	C_f*	Increment %	Δf_e	f_e (ft^2)
Fuselage	1377.2	0.001883		2.7878	
3-Dimensional Effects				0.3536	
Excrescences				0.2326	
Canopy				0.2195	
Afterbody (Base Drag)				0.1609	
					3.7544
Wing	1480.9	0.002381		3.5260	
3-D Effects				1.1773	
Excrescences				0.1980	
Gaps (flaps, slats ailerons, spoilers)				0.3574	
Body Interference				0.8986	
					6.1573
Horizontal Tail	438.7	0.002543		1.1156	
3-D Effects				0.3408	
Excrescences and gaps				0.1300	
Interference				0.6891	
					2.2755
Vertical Tail	428.0	0.002334		0.9990	
3-D Effects				0.2786	
Excrescences and gaps				0.1142	
Interference				0.0483	
					1.4401
Rotor Nacelles	479.0	0.002028		0.9714	
3-D Effects (per nacelle)				0.0788	
Excrescences				0.2237	
Interference				0.1208	
Blades Folded				0.2963	TOTAL 3.3820
Engine Nacelles	314.4	0.002248		0.7068	
Effects of Boattail (per nacelle)				0.0581	
Excrescences				0.1159	
Interference				1.0226	
Inlets				0.3441	TOTAL 4.4950
Landing Gear Pod	434.0	0.002153		0.9344	
3-D Effects				0.1124	
Excrescences				0.2781	
Interference				0.2781	
					1.6030
Miscellaneous					
Roughness (% $\Sigma C_f A_{WET}$)		*R_e/ft = 2.3352×10^6		0.8345	
Cooling				0.5600	
Trim				0.0795	
Air Conditioning				0	
					1.4740
TOTALS (ft^2)	5745.5	0.002214			24.581

TABLE XLII. MINIMUM PARASITE DRAG BREAKDOWN FOR DESIGN POINT III MULTIMISSION AIRCRAFT IN RESCUE ROLE

Component	Wetted Area	C_f*	Increment % Δf_e	f_e (ft^2)
Fuselage	1069.7	0.001903	2.1883	
3-Dimensional Effects			0.1853	
Excrescences			0.1761	
Canopy			0.1156	
Afterbody (Base Drag)			0.3223	
				2.9876
Wing	1491.6	0.002381	3.5515	
3-D Effects			1.1858	
Excrescences			0.1994	
Gaps (flaps, slats ailerons, spoilers)			0.3600	
Body Interference			0.8986	
				6.1953
Horizontal Tail	438.7	0.002543	1.1156	
3-D Effects			0.3408	
Excrescences and gaps			0.1300	
Interference			0.6891	
				2.2755
Vertical Tail	428.0	0.002334	0.9990	
3-D Effects			0.2786	
Excrescences and gaps			0.1142	
Interference			0.0483	
				1.4401
Rotor Nacelles	679.0	0.002028	0.9714	
3-D Effects (per nacelle)			0.0788	
Excrescences			0.2237	
Interference			0.1208	
Blades Folded			0.2963	TOTAL 3.3820
Engine Nacelles	314.4	0.002248	0.7068	
Effects of Boattail (per nacelle)			0.0581	
Excrescences			0.1150	
Interference			1.0226	
Inlets			0.3441	TOTAL 4.4950
Landing Gear Pod	287.0	0.002325	0.6673	
3-D Effects			0.5511	
Excrescences			0.3163	
Interference			0.3163	
				1.8510
Miscellaneous				
Roughness (% $\Sigma C_f A_{WET}$)		*R_e/ft = 1.9291×10^6	0.7785	
Cooling			0.5600	
Trim			0.0795	
Air Conditioning			0	
				1.4180
TOTALS (ft^2)	5301.8	0.002240		24.045

TABLE XLIII. MINIMUM PARASITE DRAG BREAKDOWN FOR DESIGN POINT IV V/STOL MEDIUM TRANSPORT AIRCRAFT

Component	Wetted Area	C_f*	Increment %	Increment Δf_e	f_e (ft^2)
<u>Fuselage</u>	2169.0	0.001955		4.4736	
3-Dimensional Effects				0.4207	
Excrescences				0.3634	
Canopy				0.2726	
Afterbody (Base Drag)				0.9278	
					6.4581
<u>Wing</u>	1647.9	0.002474		4.0769	
3-D Effects				1.3612	
Excrescences				0.2289	
Gaps (flaps, slats ailerons, spoilers)				0.2260	
Body Interference				1.1542	
					7.0872
<u>Horizontal Tail</u>	561.9	0.002657		1.4930	
3-D Effects				0.4560	
Excrescences and gaps				0.1740	
Interference				0.7701	
					2.8931
<u>Vertical Tail</u>	321.8	0.002454		0.7897	
3-D Effects				0.2202	
Excrescences and gaps				0.0903	
Interference				0.0496	
					1.1498
<u>Rotor Nacelles</u>	560.1	0.002144		1.2009	
3-D Effects (per nacelle)				0.1146	
Excrescences				0.2799	
Interference				0.3112	
Blades Folded				0.3709	TOTAL
					4.5550
<u>Engine Nacelles</u>	308.0	0.002364		0.7281	
Effects of Boattail (per nacelle)				0.0581	
Excrescences				0.0788	
Interference				0.8837	
Inlets				0.3274	TOTAL
					4.1522
<u>Landing Gear Pod</u>	287.0	0.002439		0.7000	
3-D Effects				0.5079	
Excrescences				0.3142	
Interference				0.3142	
					1.8363
<u>Miscellaneous</u>					
Roughness (% $\Sigma C_f A_{WET}$)		*R_e/ft = 1.7514×10^6		1.0154	
Cooling				0.8890	
Trim				0.0957	
Air Conditioning					
					2.0001
TOTALS (ft^2)	6723.8	0.002289			30.132

TABLE XLIV. MINIMUM PARASITE DRAG BREAKDOWN FOR DESIGN POINT V MULTIMISSION AIRCRAFT IN RESCUE ROLE

Component	Wetted Area	C_f*	Increment % Δf_e	f_e (ft^2)
Fuselage	1484.0	0.001949	3.1093	
3-Dimensional Effects			0.1915	
Excrescences			0.2452	
Canopy			0.1156	
Afterbody (Base Drag)			0.2747	
				3.9363
Wing	2132.7	0.002429	5.1803	
3-D Effects			1.7296	
Excrescences			0.2909	
Gaps (flaps, slats ailerons, spoilers)			0.3426	
Body Interference			1.5446	
				9.0880
Horizontal Tail	818.3	0.002545	2.0826	
3-D Effects			0.6361	
Excrescences and gaps			0.2428	
Interference			1.1139	
				4.0754
Vertical Tail	431.6	0.002452	1.1490	
3-D Effects			0.3205	
Excrescences and gaps			0.1313	
Interference			0.0509	
				1.6517
Rotor Nacelles	691.7	0.002115	1.4630	
3-D Effects (per nacelle)			0.1428	
Excrescences			0.3416	
Interference			0.4048	
Blades Folded			0.4527	TOTAL 5.6098
Engine Nacelles	510.6	0.002290	1.1693	
Effects of Boattail (per nacelle)			0.0941	
Excrescences			0.1893	
Interference			1.3271	
Inlets			0.5478	TOTAL 6.6552
Landing Gear Pod				
3-D Effects				
Excrescences				
Interference				
Miscellaneous				
Roughness(% $\Sigma C_f A_{WET}$)		*R_e/ft = 1.7514×10^6	1.0952	
Cooling			0.7426	
Trim			0.0993	
Air Conditioning			0	
				1.9371
TOTALS (ft^2)	7271.2	0.002309		32.9537

TABLE XLV. MINIMUM PARASITE DRAG BREAKDOWN FOR DESIGN POINT V MULTIMISSION AIRCRAFT IN CAPSULE RECOVERY ROLE

Component	Wetted Area	C_f*	Increment %	Δf_e	f_e (ft^2)
Fuselage	2166.1	0.001850		4.2277	
3-Dimensional Effects				0.3976	
Excrescences				0.3434	
Canopy				0.2726	
Afterbody (Base Drag)				0.9277	
					6.1690
Wing	2061.3	0.002296		4.7327	
3-D Effects				1.5802	
Excrescences				0.2658	
Gaps (flaps, slats ailerons, spoilers)				0.3129	
Body Interference				1.5446	
					8.4362
Horizontal Tail	818.3	0.002438		2.0155	
3-D Effects				0.6156	
Excrescences and gaps				0.2350	
Interference				1.1139	
					3.9800
Vertical Tail	468.6	0.002314		1.0843	
3-D Effects				0.3024	
Excrescences and gaps				0.1239	
Interference				0.0509	
					1.5615
Rotor Nacelles	691.7	0.002000		1.3834	
3-D Effects (per nacelle)				0.1350	
Excrescences				0.3231	
Interference				0.4048	
Blades Folded				0.4281	TOTAL
					5.3488
Engine Nacelles	510.6	0.002166		1.1060	
Effects of Boattail (per nacelle)				0.0941	
Excrescences				0.1214	
Interference				1.3270	
Inlets				0.5478	TOTAL
					6.3926
Landing Gear Pod	873.0	0.002083		1.8289	
3-D Effects				0.2526	
Excrescences				0.5524	
Interference				0.5524	
					3.1863
Miscellaneous					
Roughness (% $\Sigma C_f A_{WET}$)		*R_e/ft = 2.3352×10^6		1.2434	
Cooling				0.7426	
Trim				0.0993	
Air Conditioning				0	
					2.0853
TOTALS (ft^2)	8796.9	0.002145			37.159

TABLE XLVI. MINIMUM PARASITE DRAG BREAKDOWN FOR DESIGN POINT V MULTIMISSION AIRCRAFT IN V/STOL MEDIUM TRANSPORT ROLE

Component	Wetted Area	C_f*	Increment % Δf_e	f_e (ft^2)
Fuselage	2166.1	0.001955	4.4676	
3-Dimensional Effects			0.4201	
Excrescences			0.3629	
Canopy			0.2726	
Afterbody (Base Drag)			0.9278	
				6.4510
Wing	2061.3	0.002429	5.0069	
3-D Effects			1.6717	
Excrescences			0.2812	
Gaps (flaps, slats ailerons, spoilers)			0.3311	
Body Interference			1.5446	
				8.8355
Horizontal Tail	818.3	0.002545	2.0826	
3-D Effects			0.6361	
Excrescences and gaps			0.2428	
Interference			1.1139	
				4.0754
Vertical Tail	431.6	0.002452	1.1490	
3-D Effects			0.3205	
Excrescences and gaps			0.1313	
Interference			0.0509	
				1.6517
Rotor Nacelles	691.7	0.002115	1.4630	
3-D Effects (per nacelle)			0.1428	
Excrescences			0.3416	
Interference			0.4048	
Blades Folded			0.4527	TOTAL 5.6098
Engine Nacelles	510.6	0.002290	1.1693	
Effects of Boattail (per nacelle)			0.0941	
Excrescences			0.1893	
Interference			1.3271	
Inlets			0.5478	TOTAL 6.6552
Landing Gear Pod	287.0	0.002493	0.7000	
3-D Effects			0.5079	
Excrescences			0.3142	
Interference			0.3142	
				1.8363
Miscellaneous				
Roughness(% $\Sigma C_f A_{WET}$)		*R_e/ft = 1.7514×10^6	1.2260	
Cooling			0.7426	
Trim			0.0993	
Air Conditioning			0	
				2.0679
TOTALS (ft^2)	8168.9	0.002286		37.1828

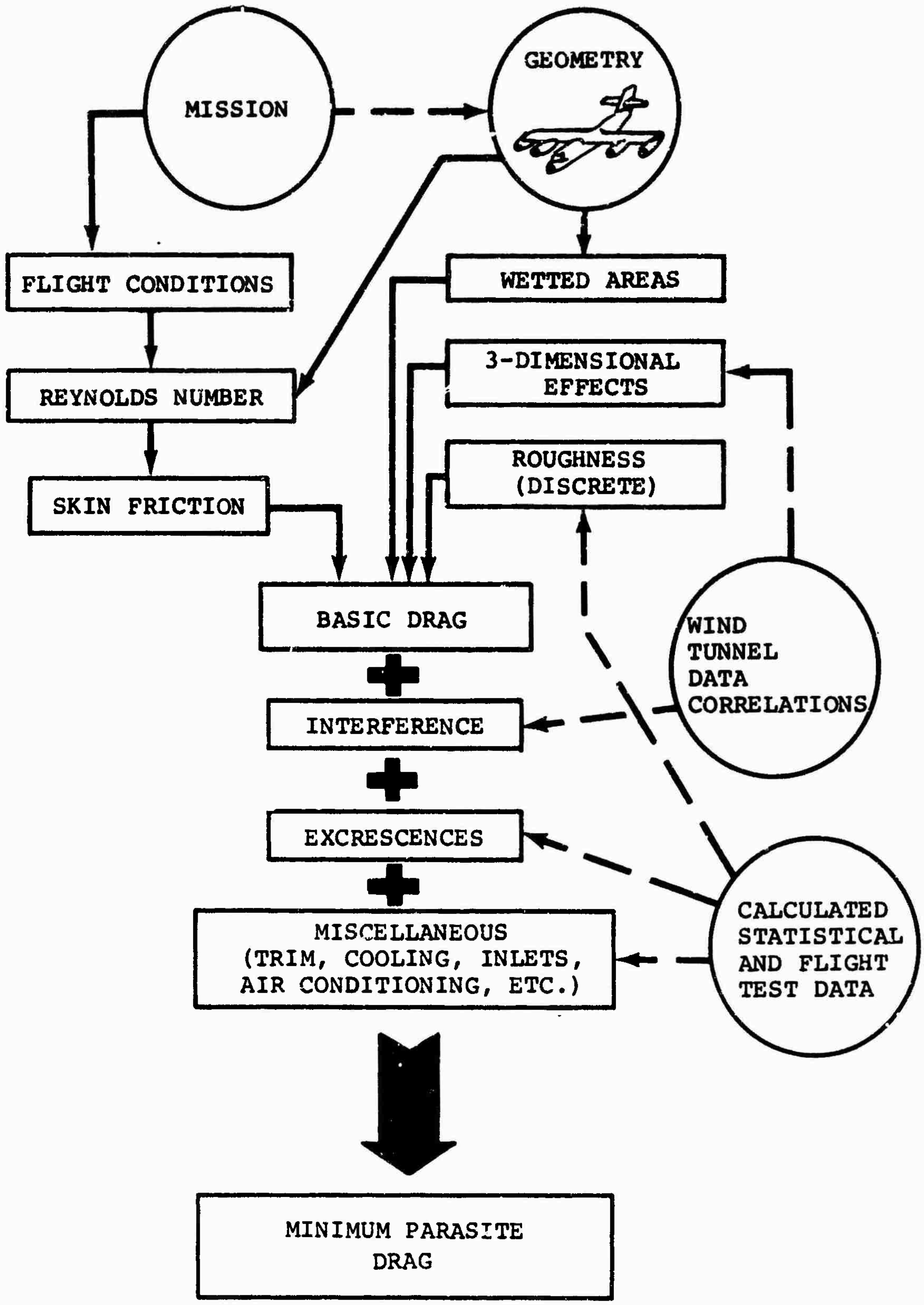


Figure 131. Minimum Parasite Drag Estimation Procedure.

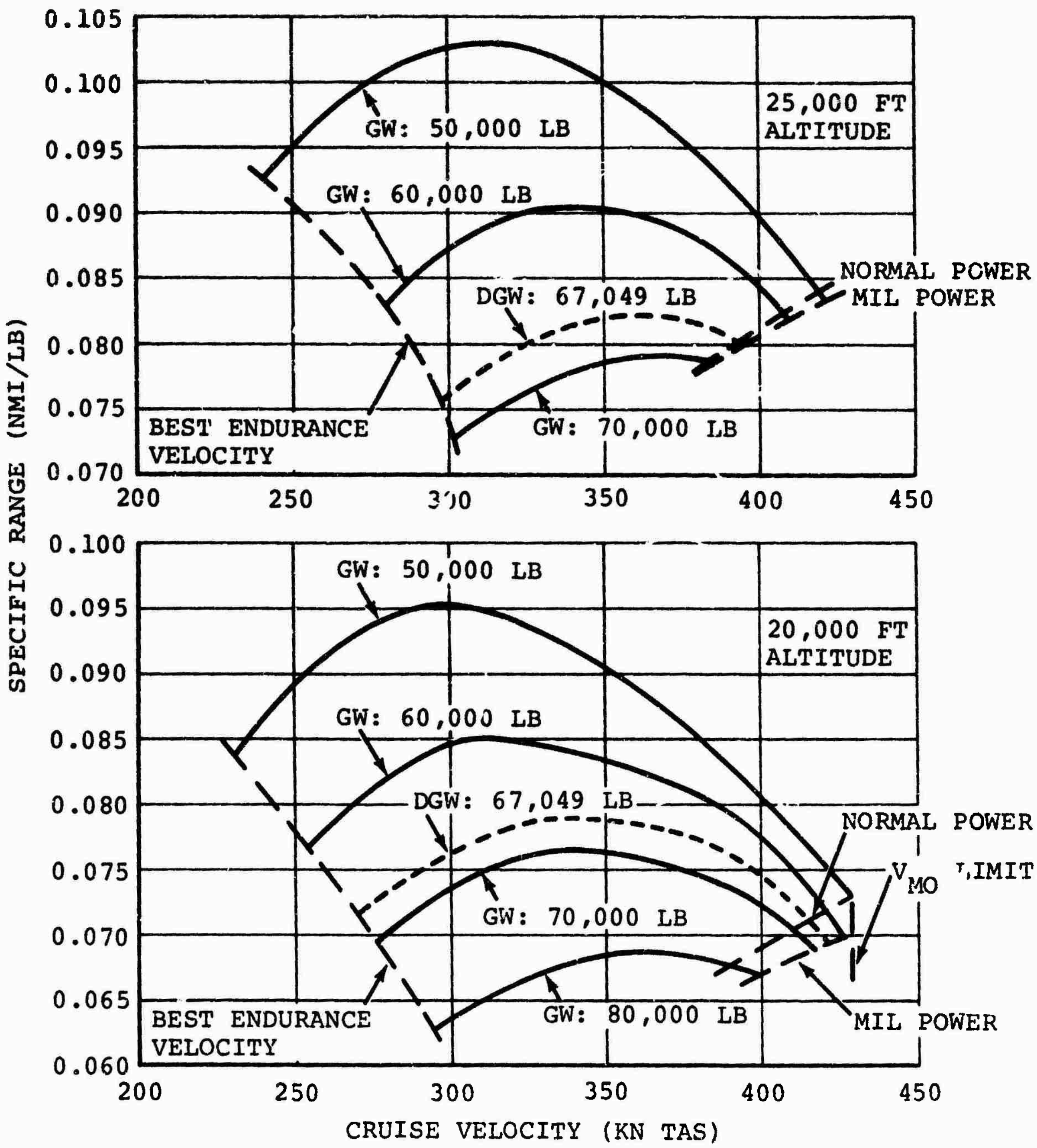


Figure 132. Design Point I Standard Day Cruise Performance (Sheet 1 of 3).

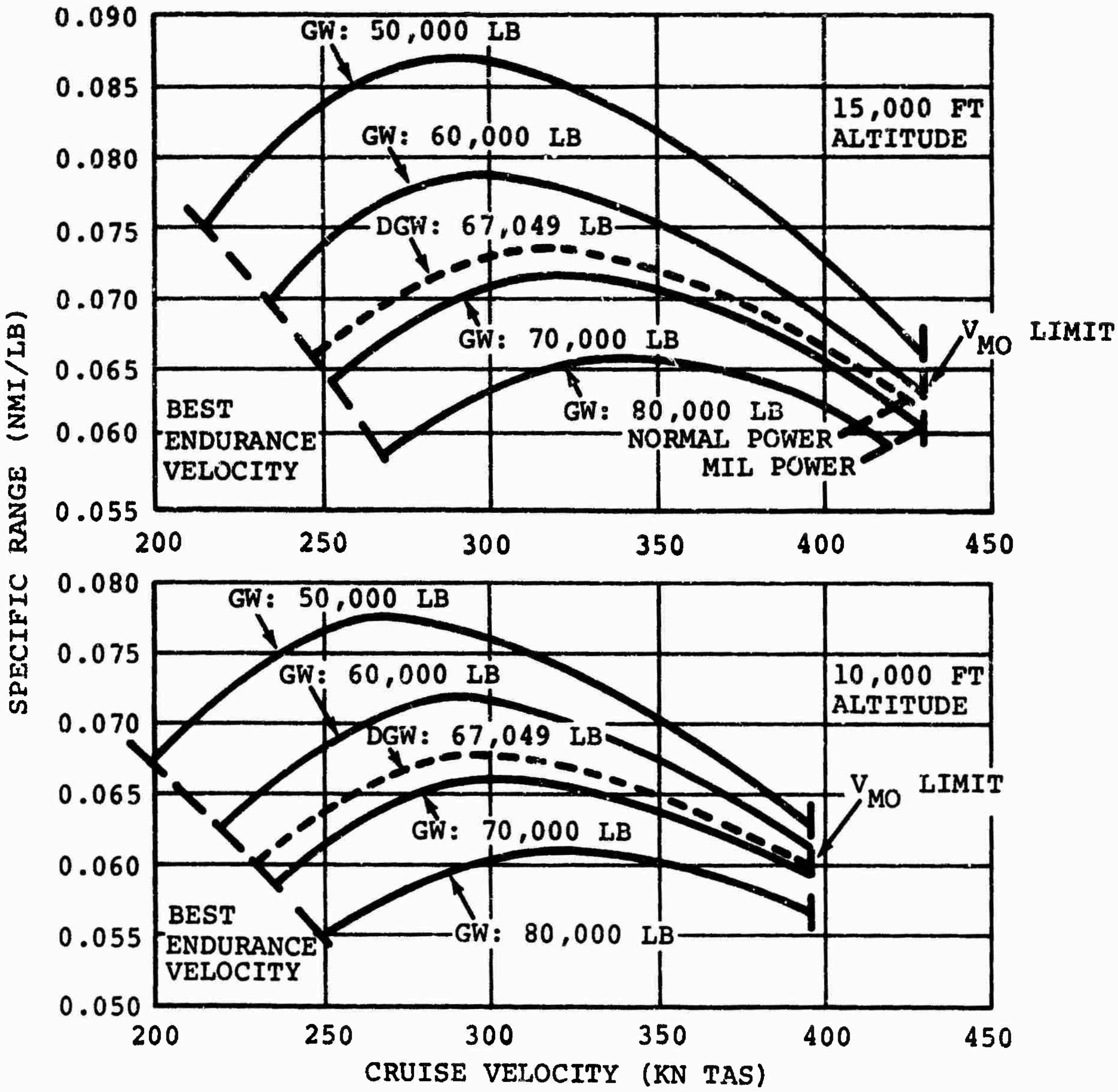


Figure 132. Design Point I Standard Day Cruise Performance (Sheet 2 of 3).

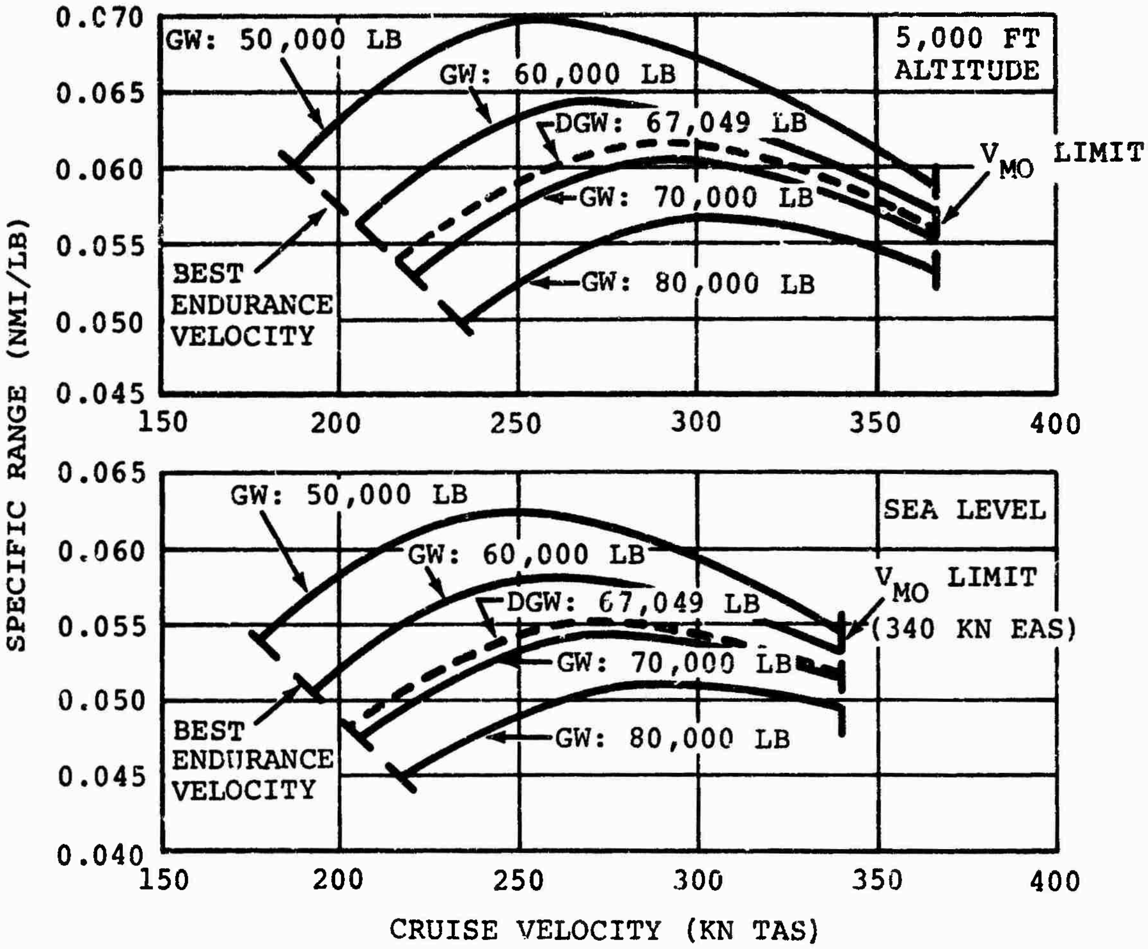


Figure 132. Design Point I Standard Day Cruise Performance (Sheet 3 of 3).

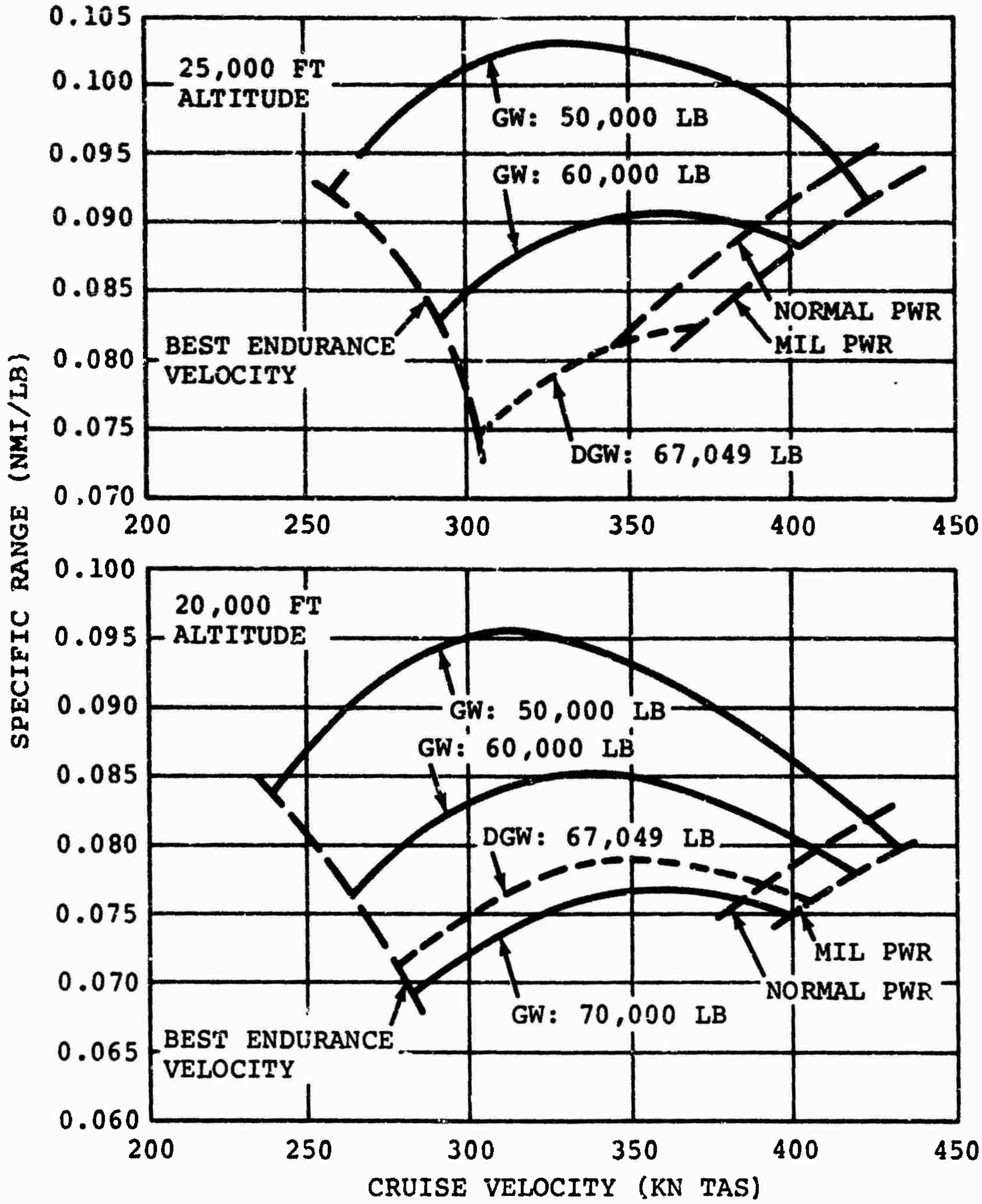


Figure 132A. Design Point I Air Force Hot Day Cruise Performance (Sheet 1 of 3).

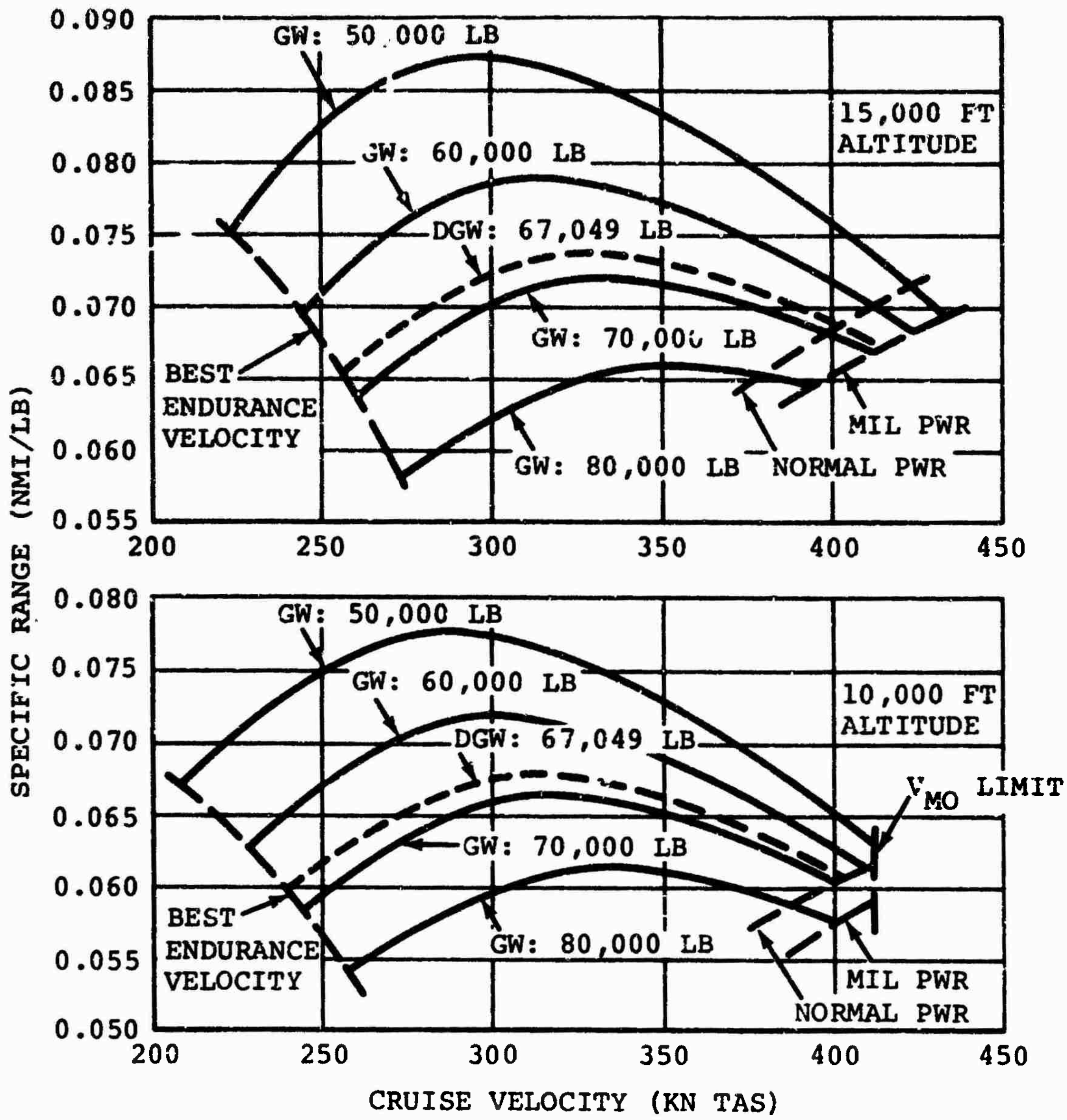


Figure 132A. Design Point I Air Force Hot Day Cruise Performance (Sheet 2 of 3).

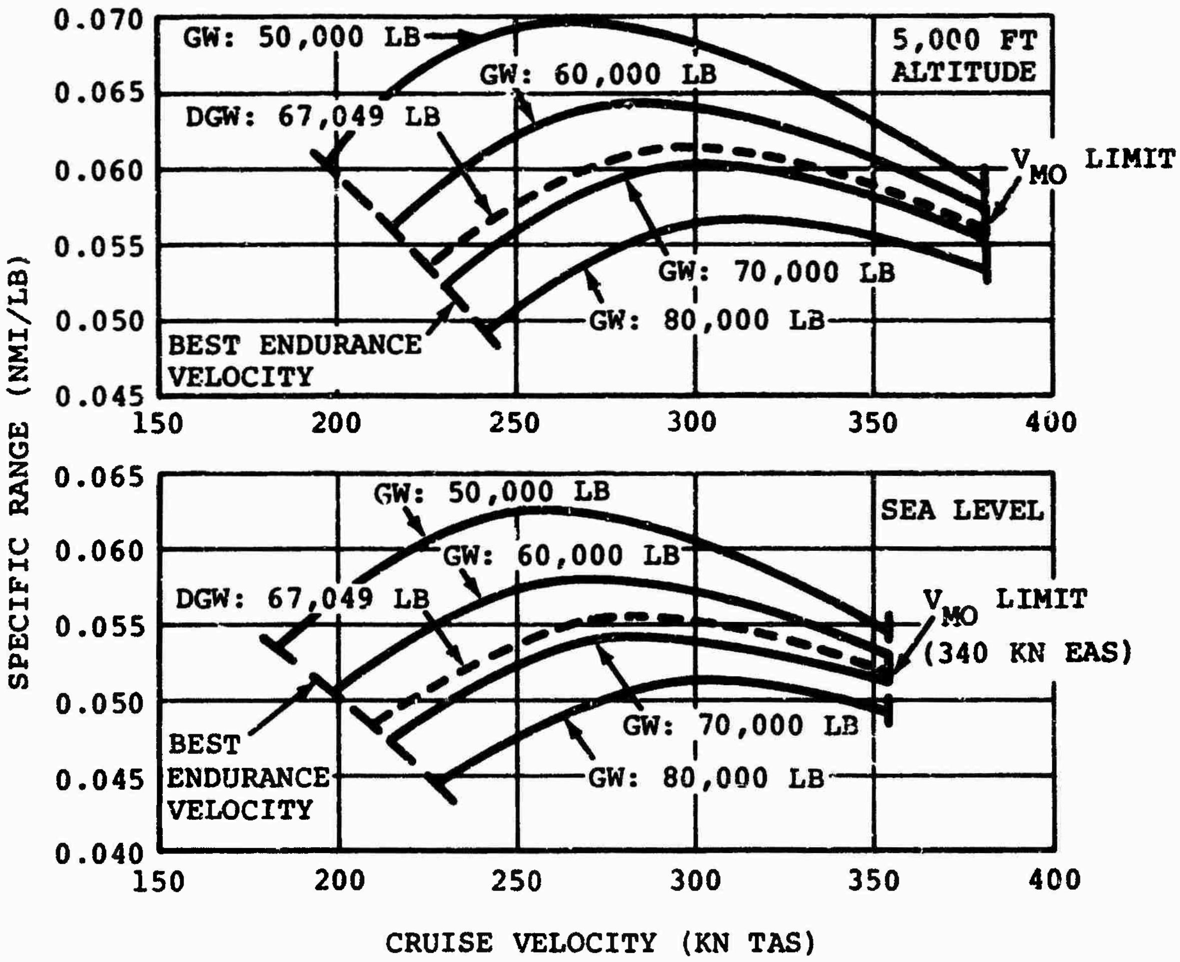


Figure 132A. Design Point I Air Force Hot Day Cruise Performance (Sheet 3 of 3).

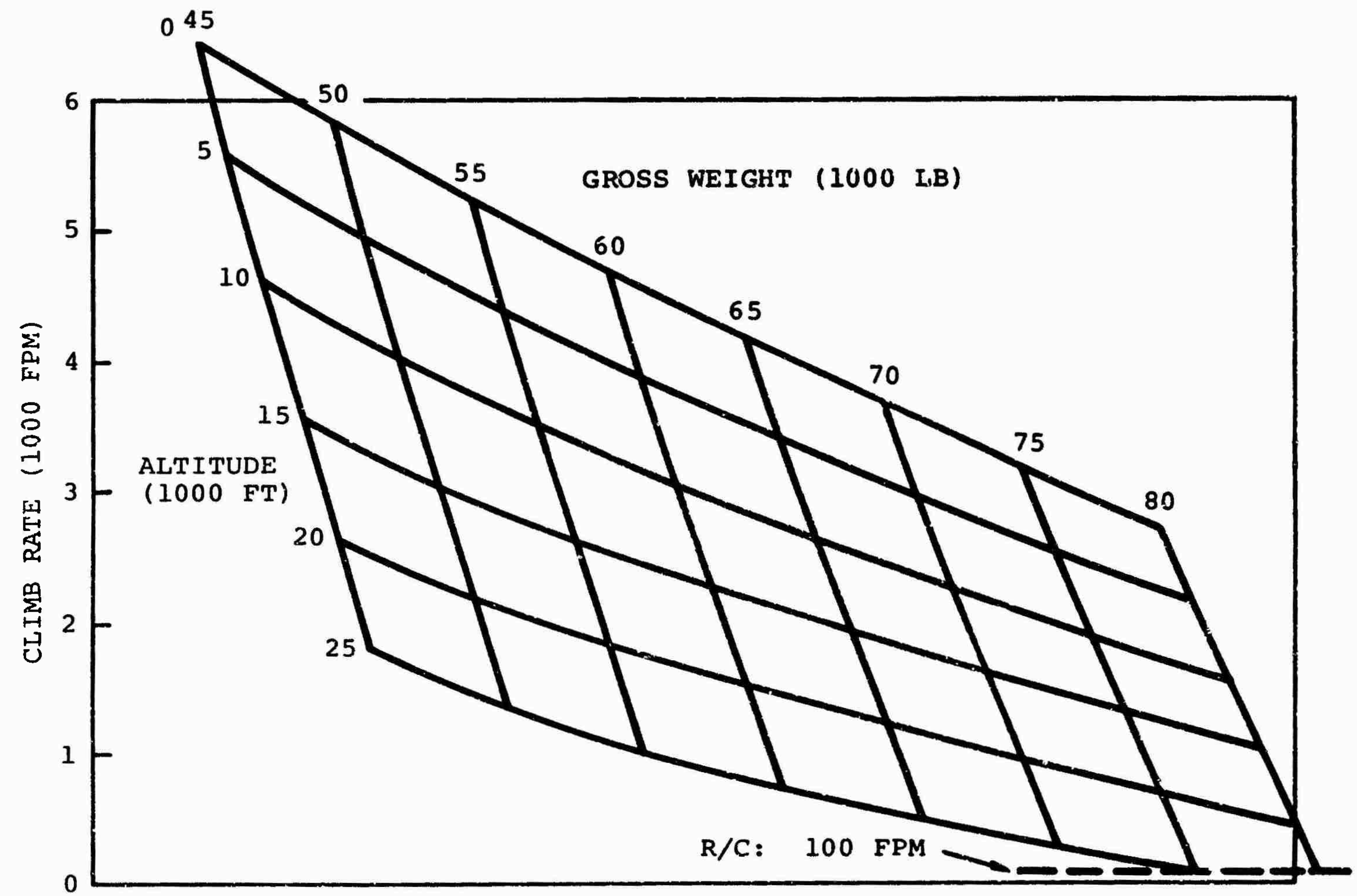


Figure 133. Design Point I Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

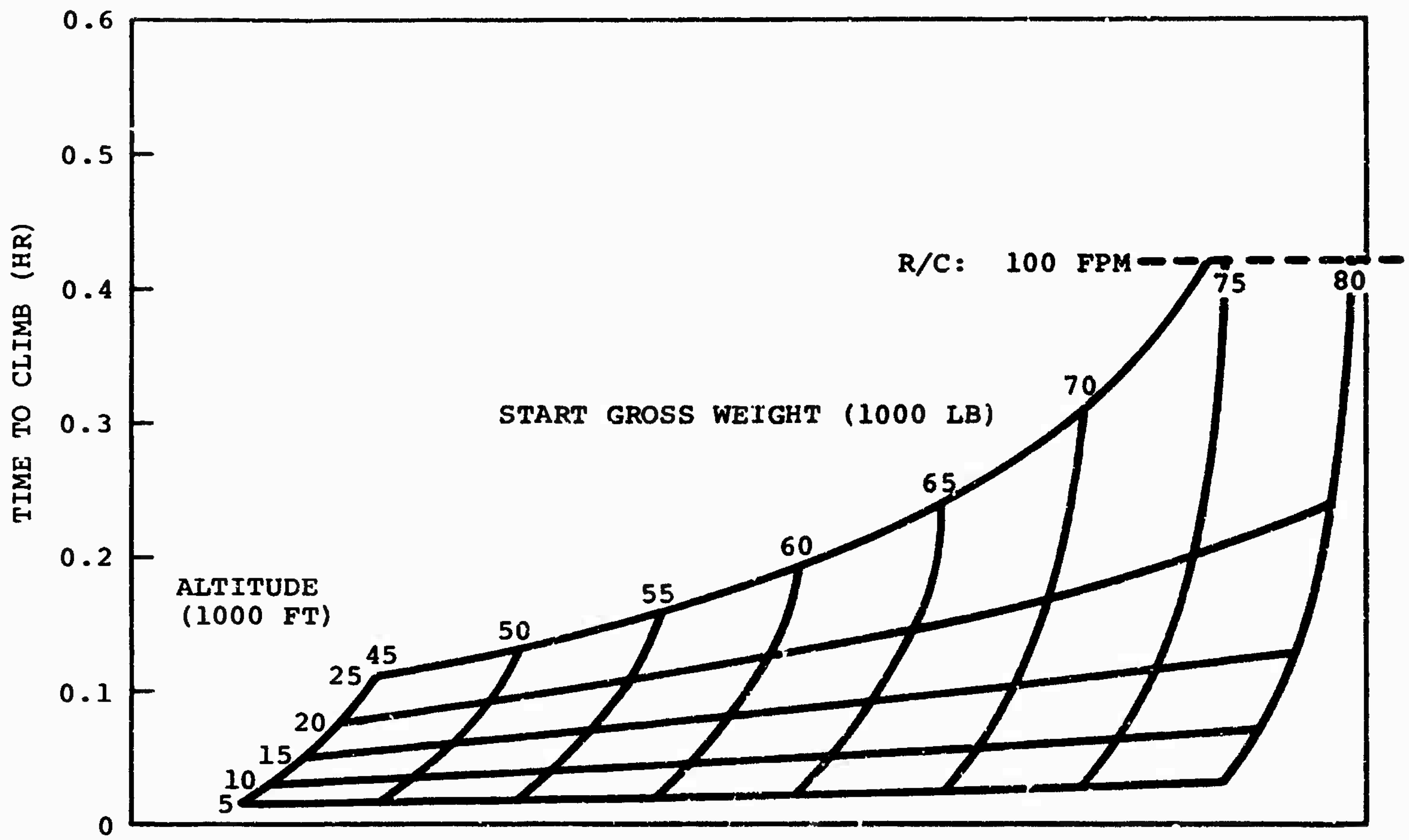


Figure 134. Design Point I Time to Climb From Sea Level at Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

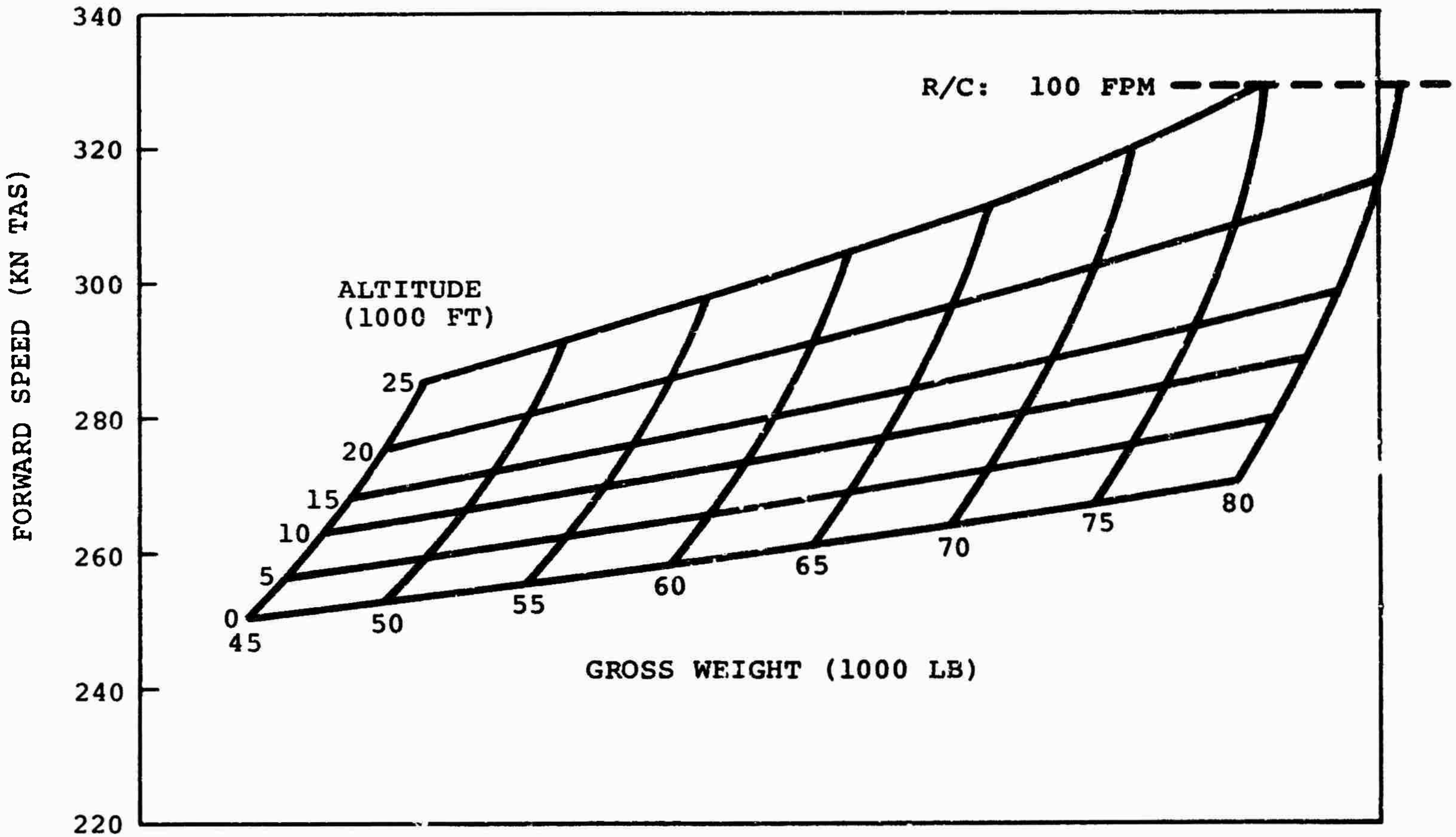


Figure 135. Design Point I Forward Speed at Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

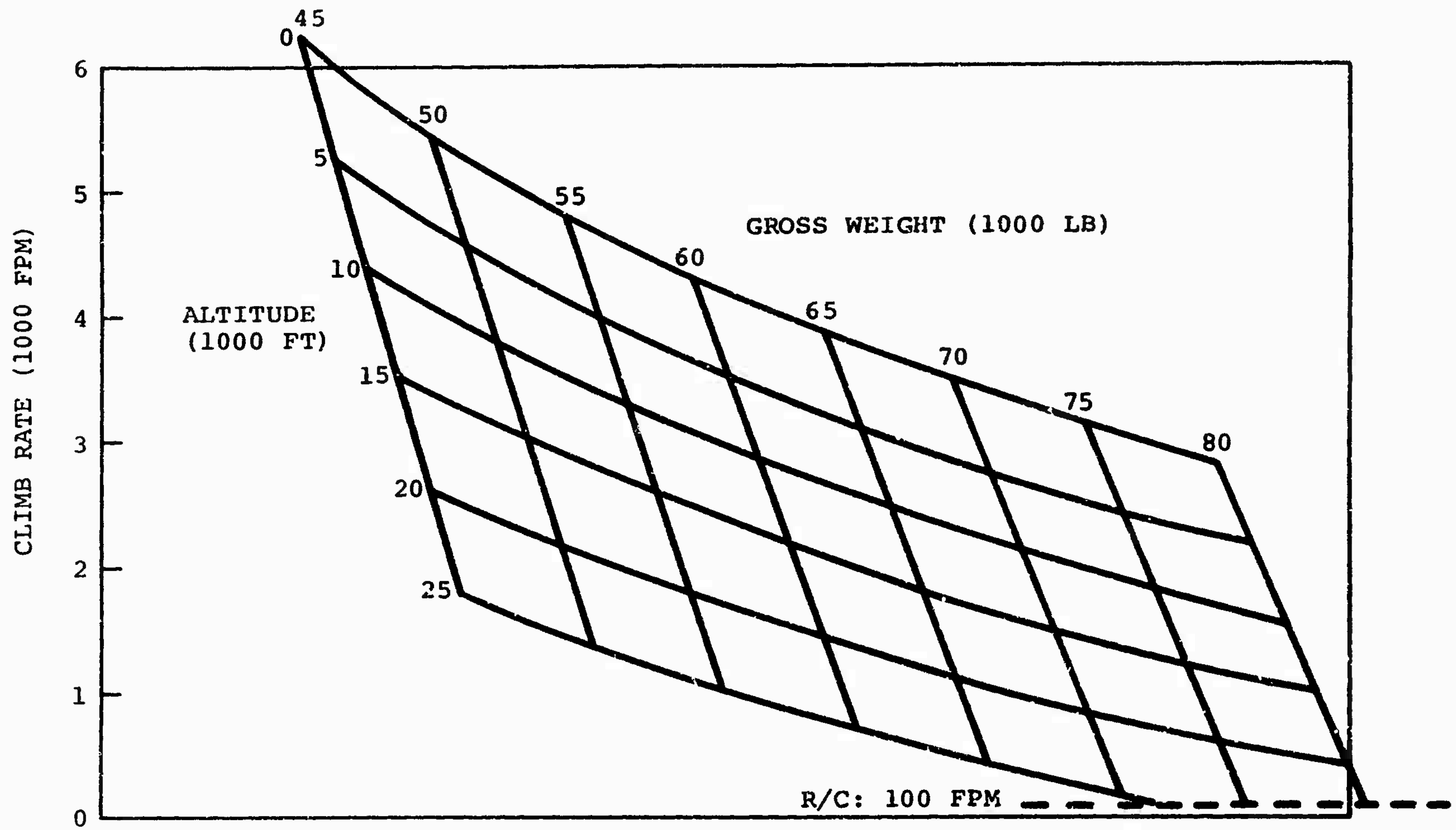


Figure 136. Design Point I Maximum Rate of Climb for Standard Day With All Engines Operating at Military Power.

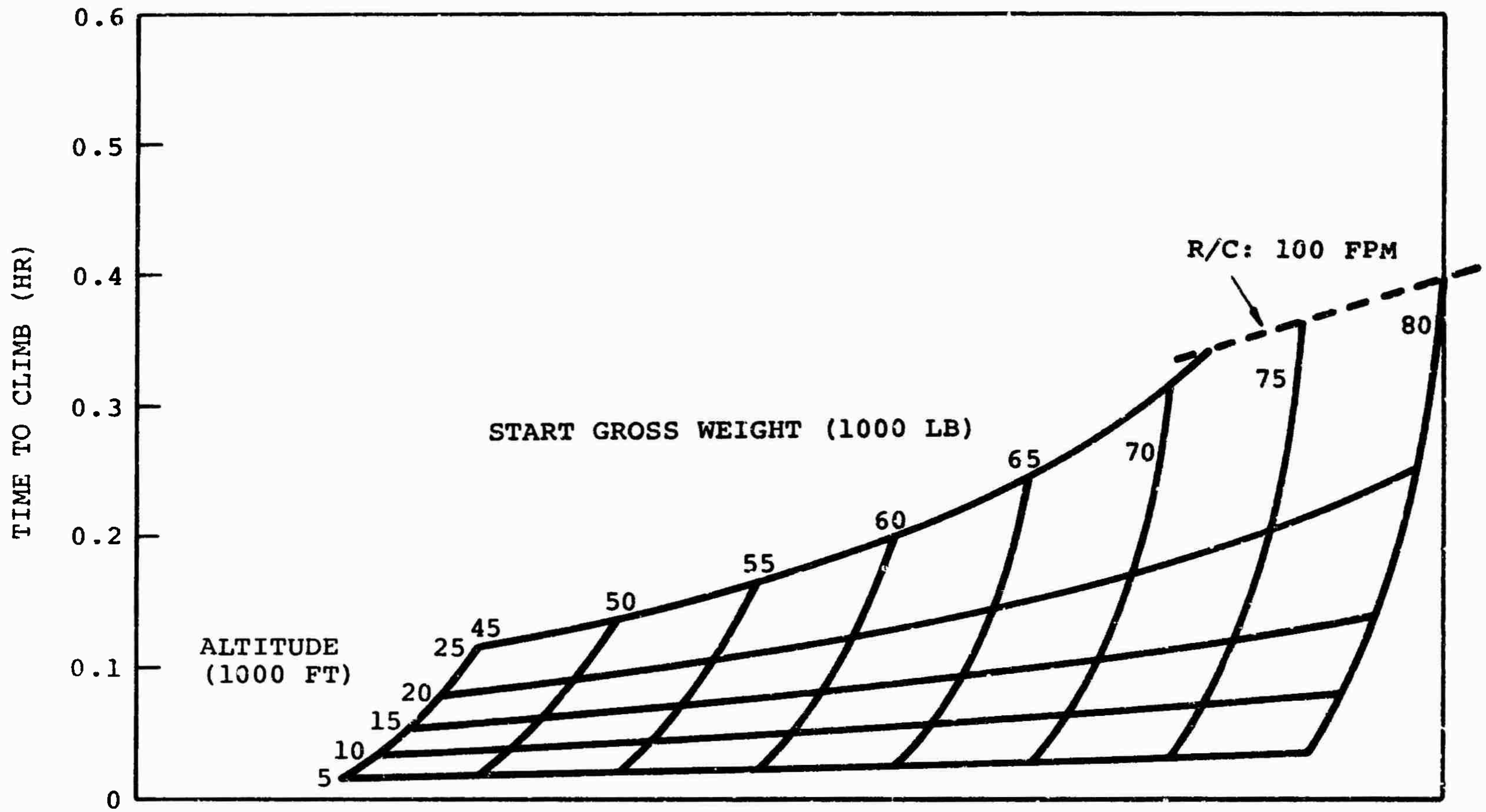


Figure 137. Design Point I Time to Climb From Sea Level at Maximum Rate of Climb for Standard Day With All Engines Operating at Military Power.

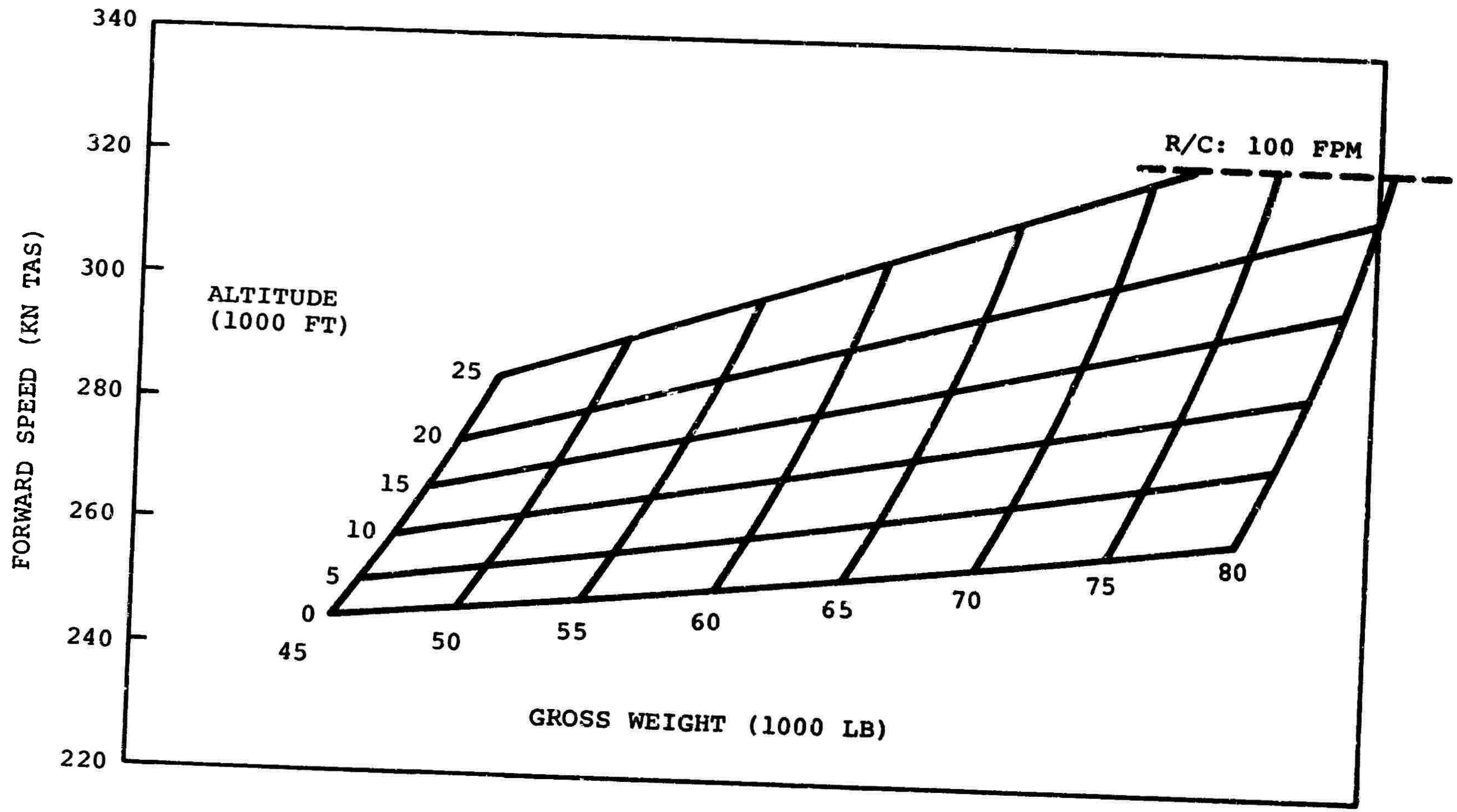


Figure 138. Design Point I Forward Speed at Maximum Rate of Climb For Standard Day With All Engines Operating at Military Power.

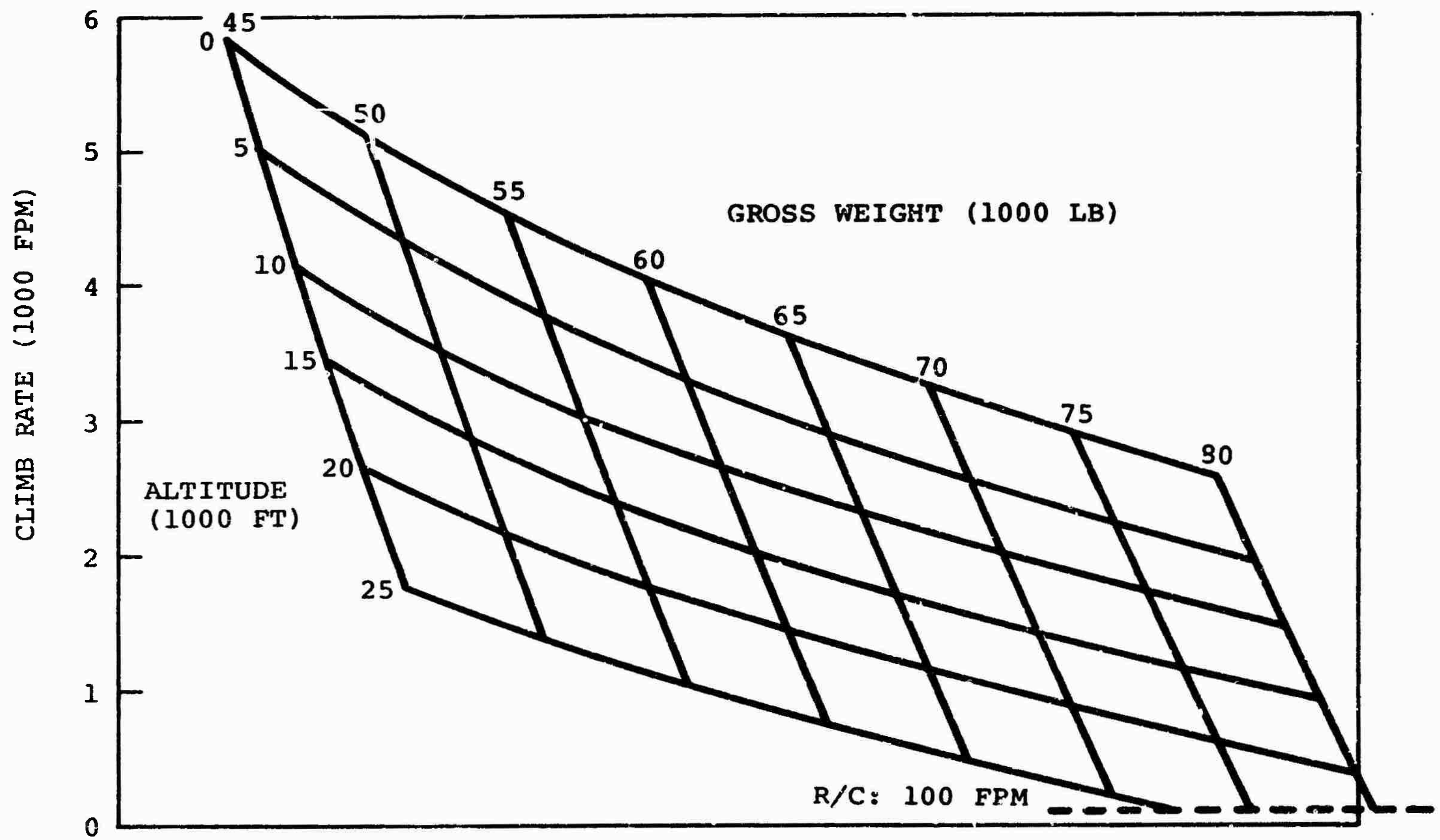


Figure 139. Design Point I Maximum Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.

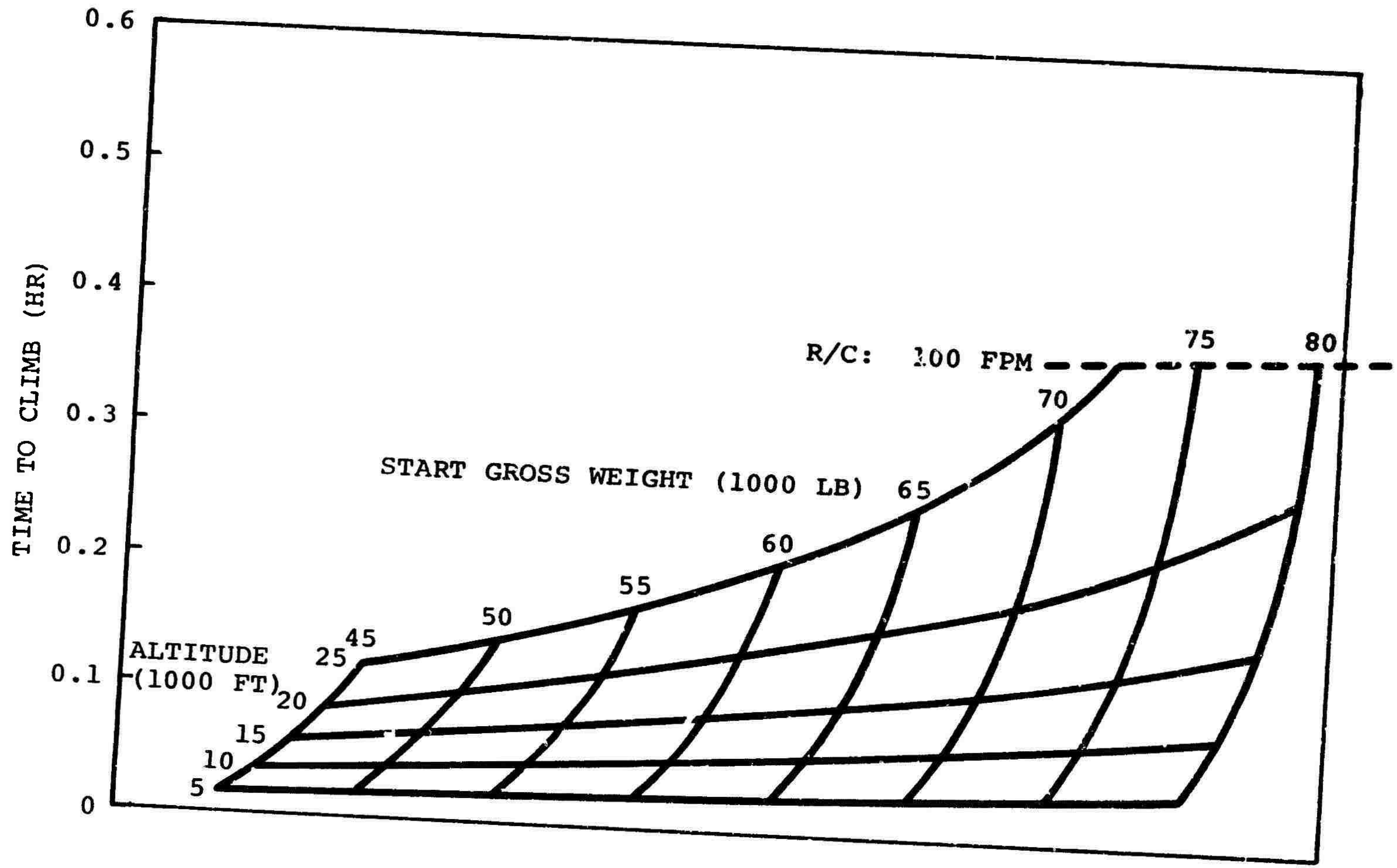


Figure 140. Design Point I Time to Climb From Sea Level at Maximum Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.

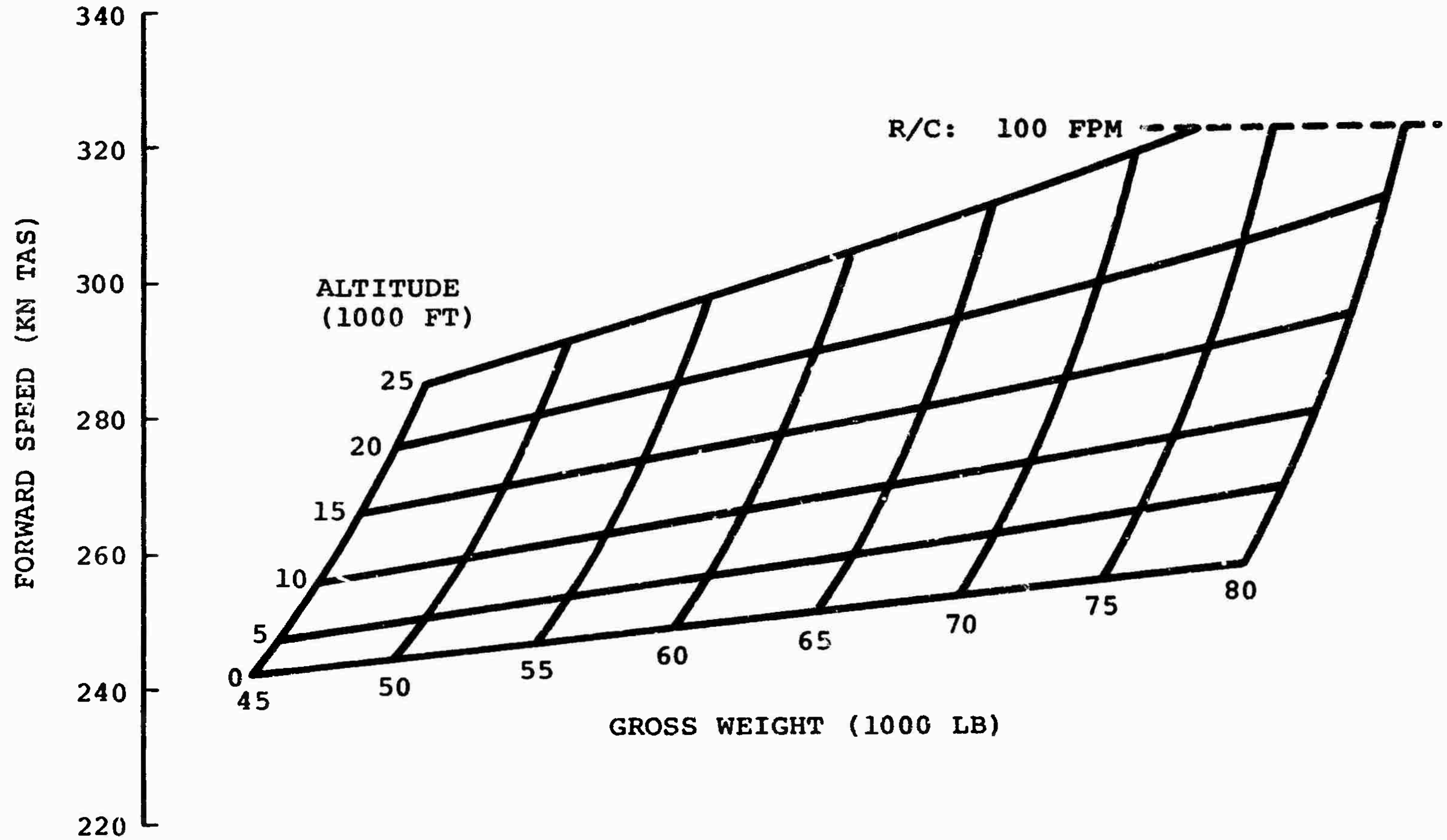


Figure 141. Design Point I Forward Speed at Maximum Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.

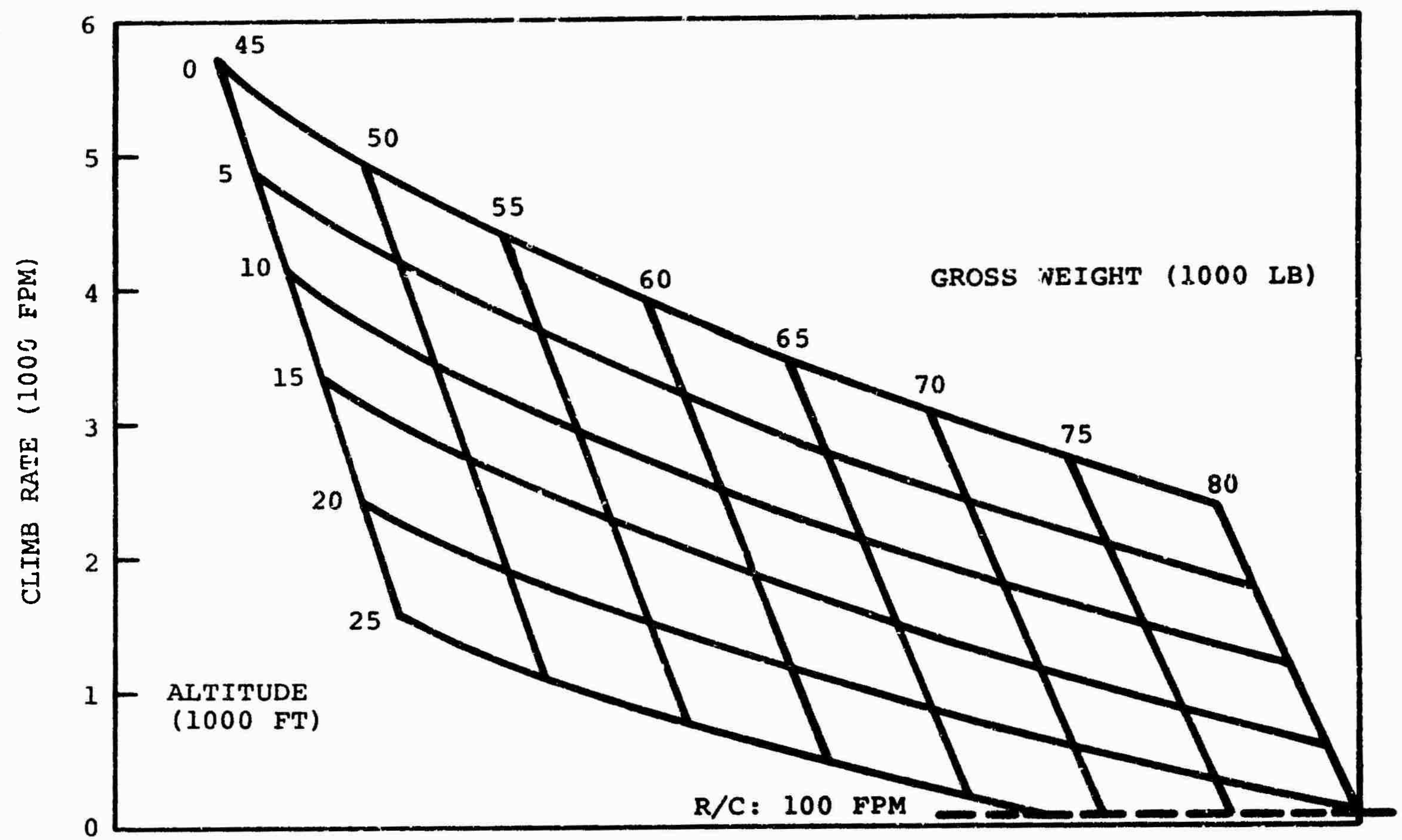


Figure 142. Design Point I Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

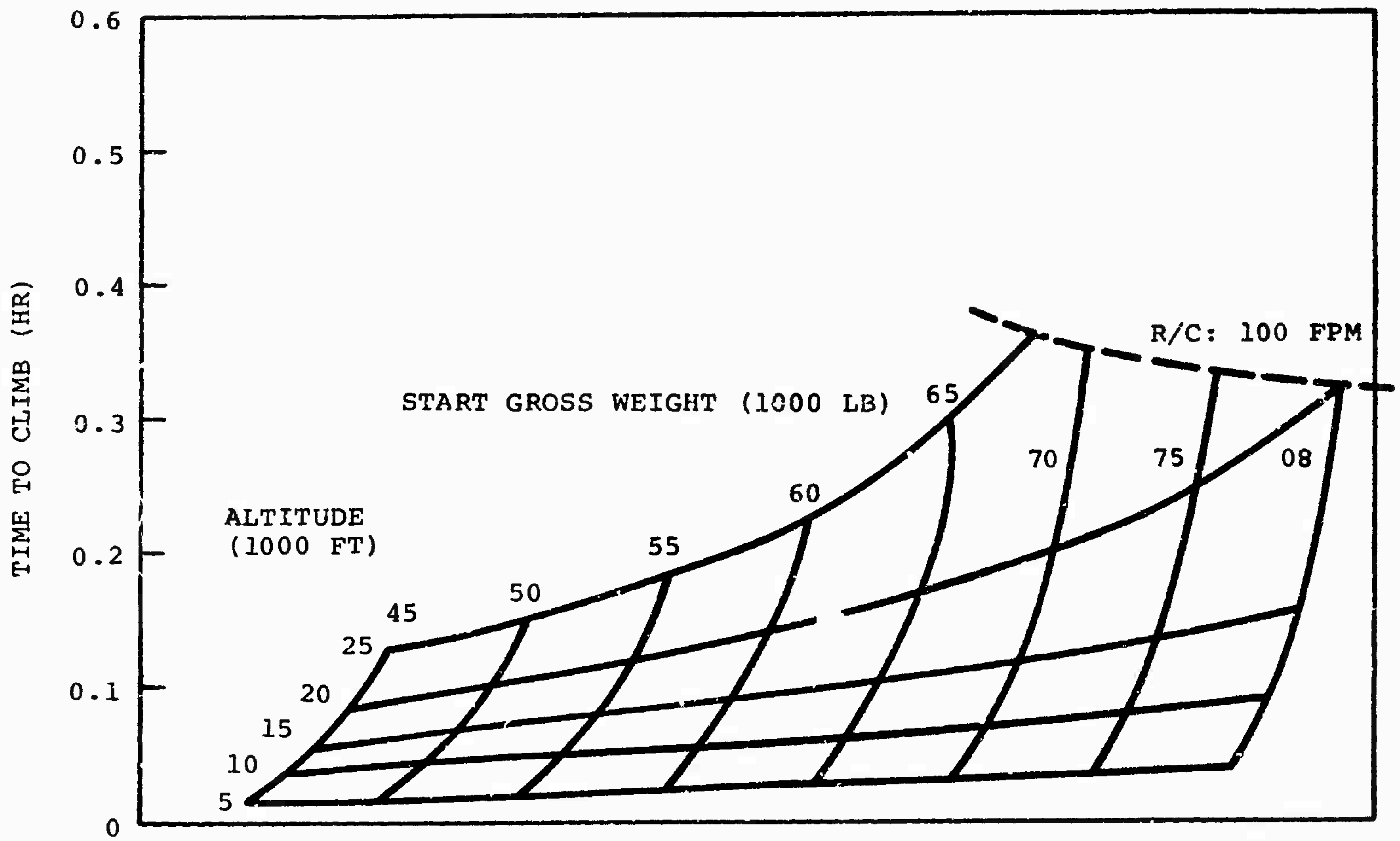


Figure 143. Design Point I Time to Climb From Sea Level at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

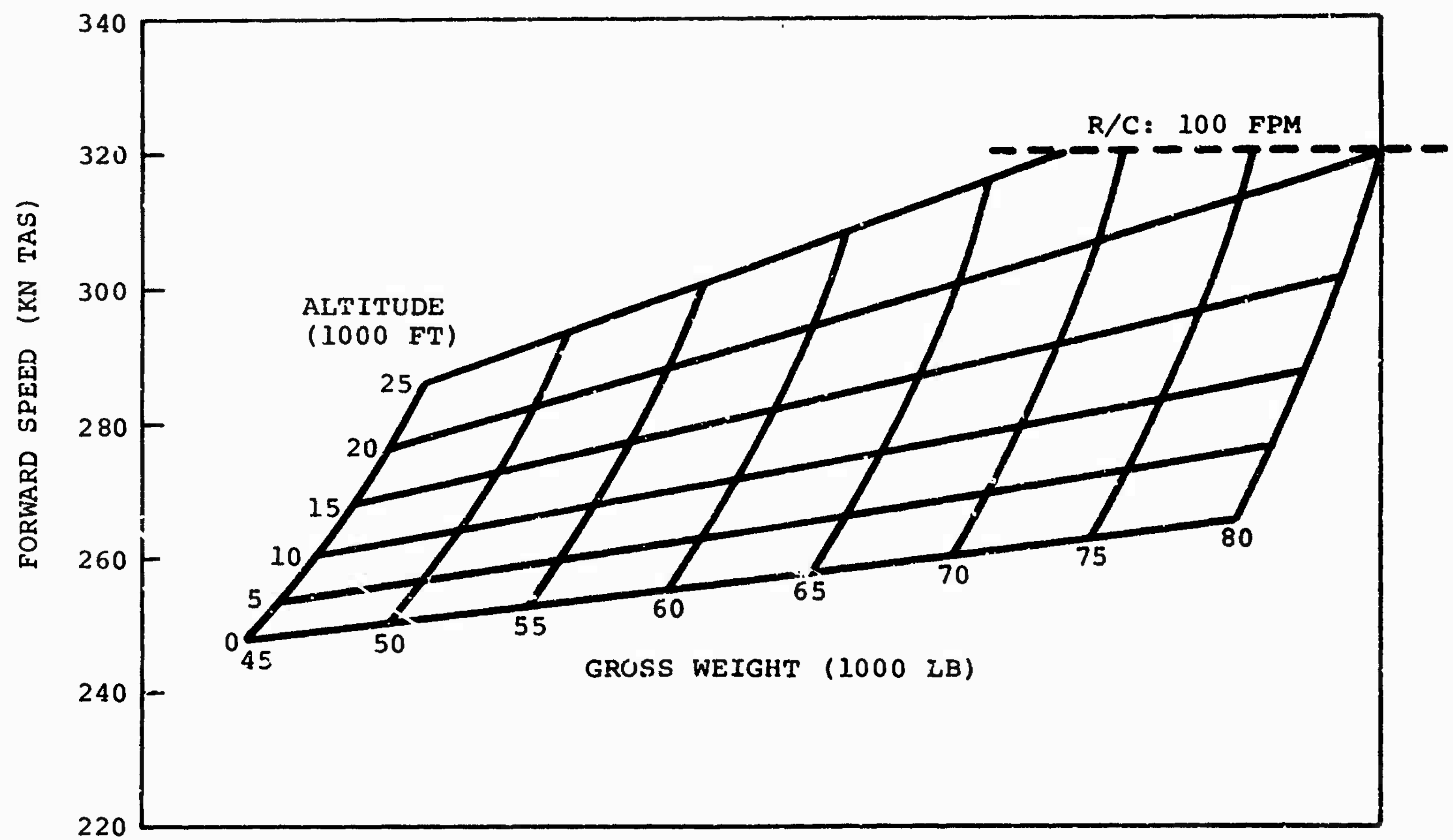


Figure 144. Design Point I Forward Speed at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

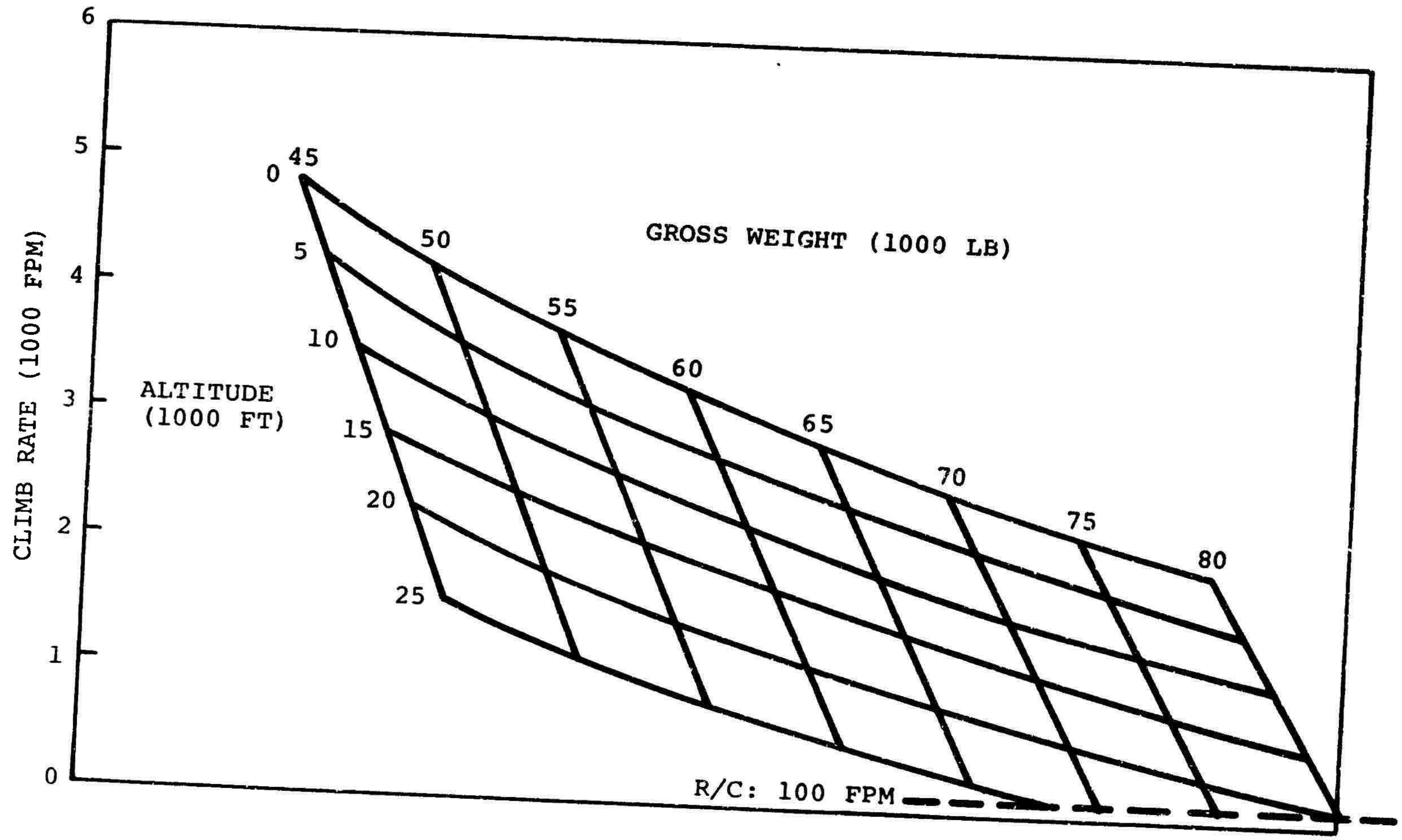


Figure 145. Design Point I Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

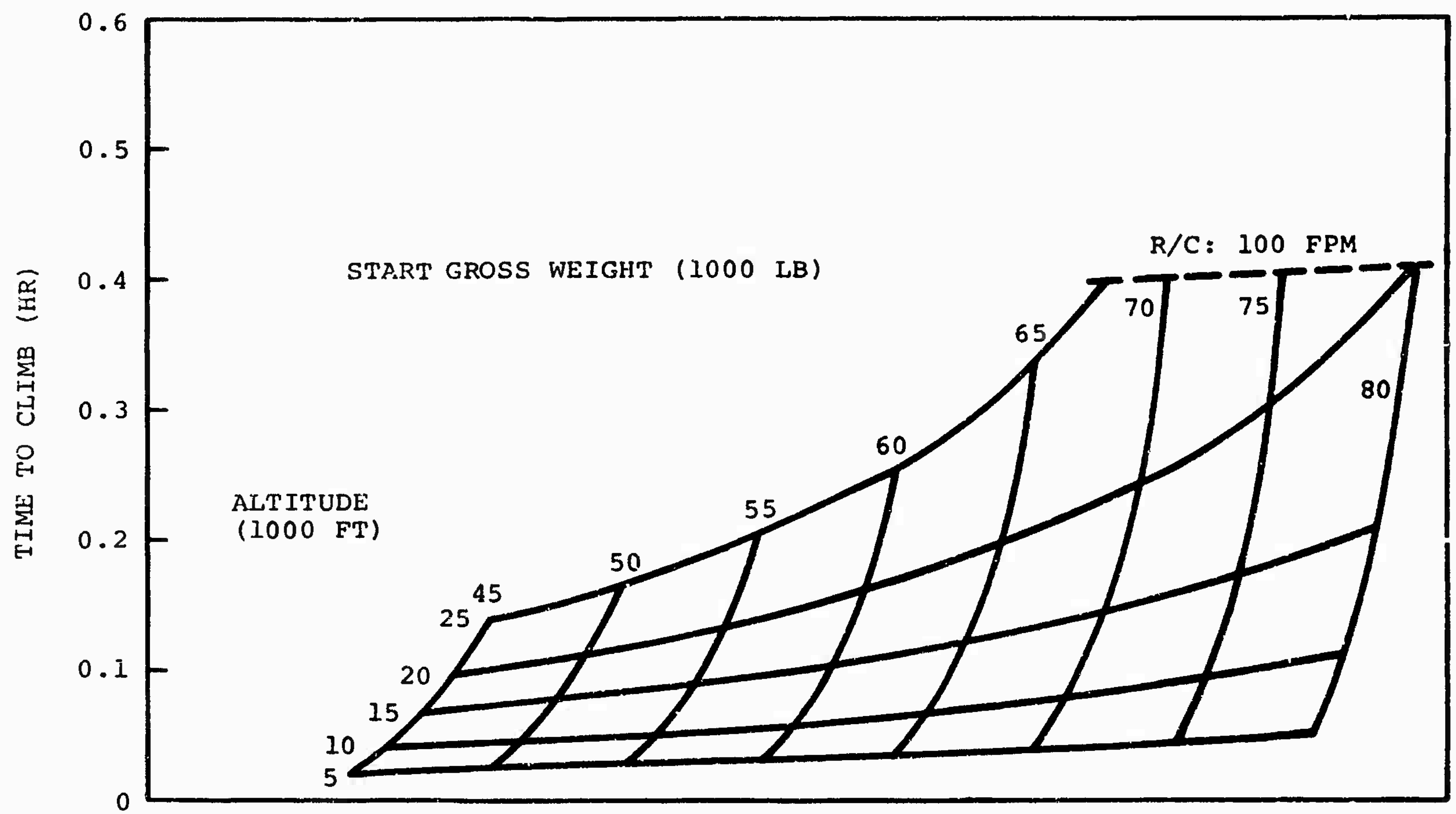


Figure 146. Design Point I Time to Climb From Sea Level at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

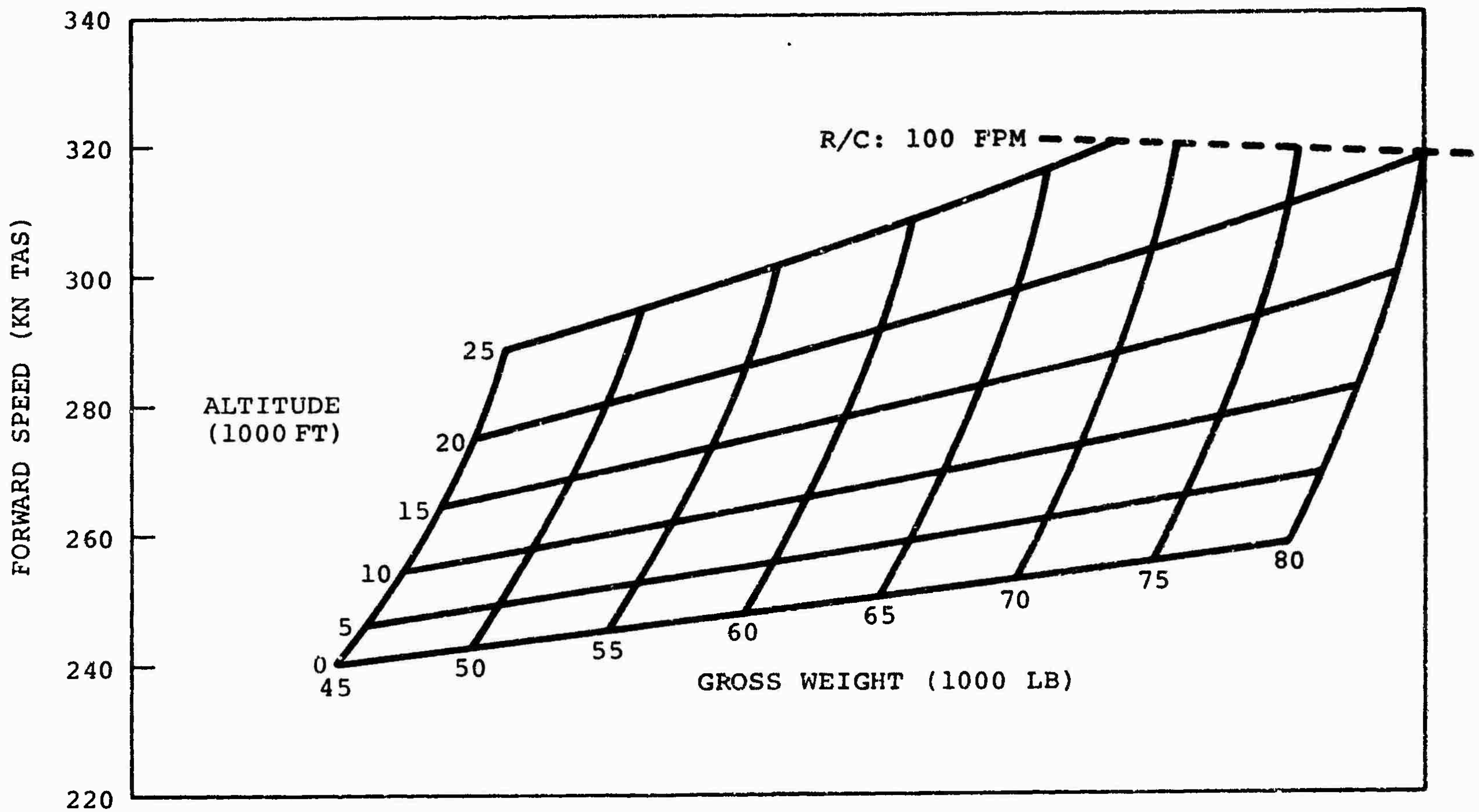


Figure 147. Design Point I Forward Speed at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

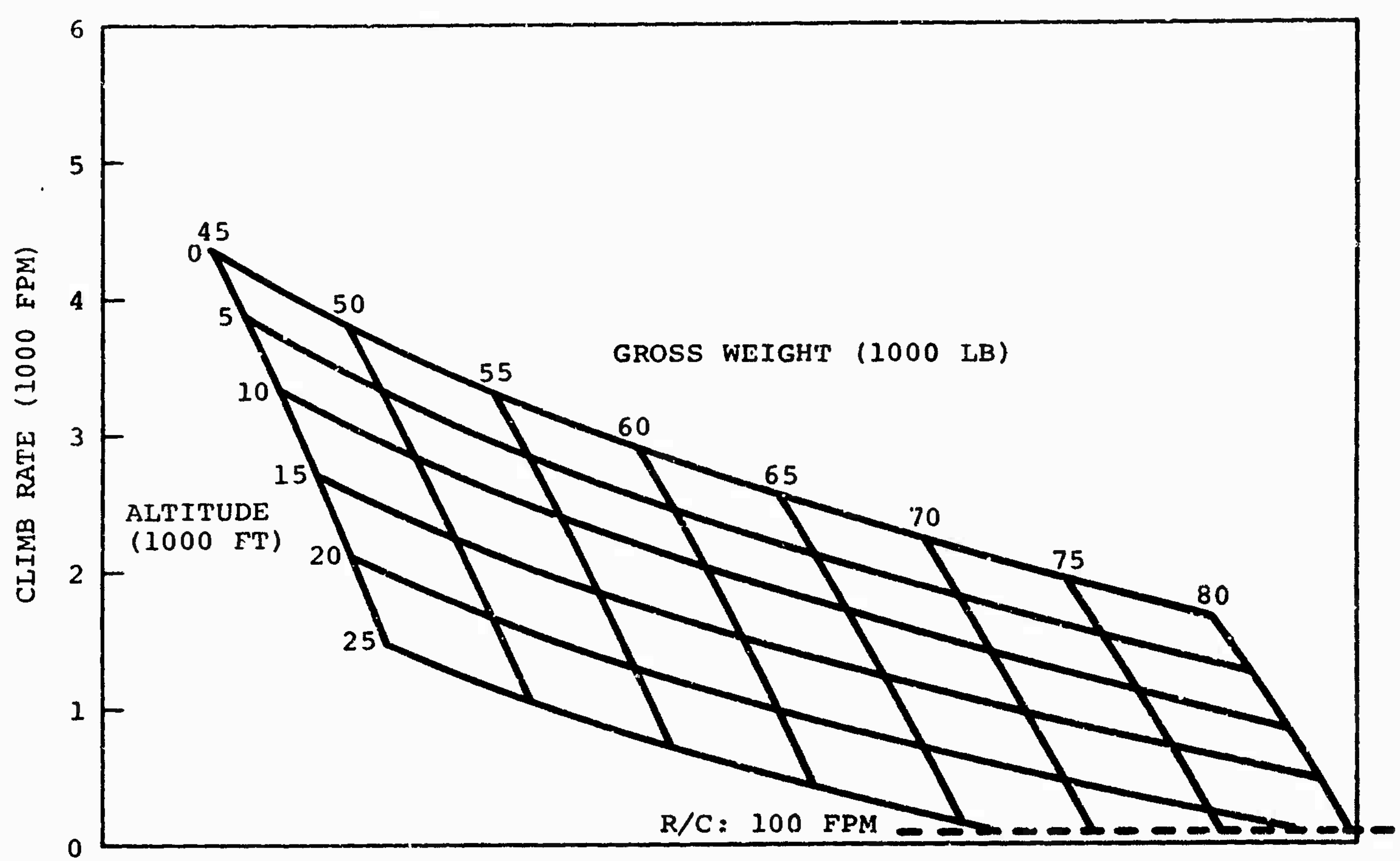


Figure 148. Design Point I Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

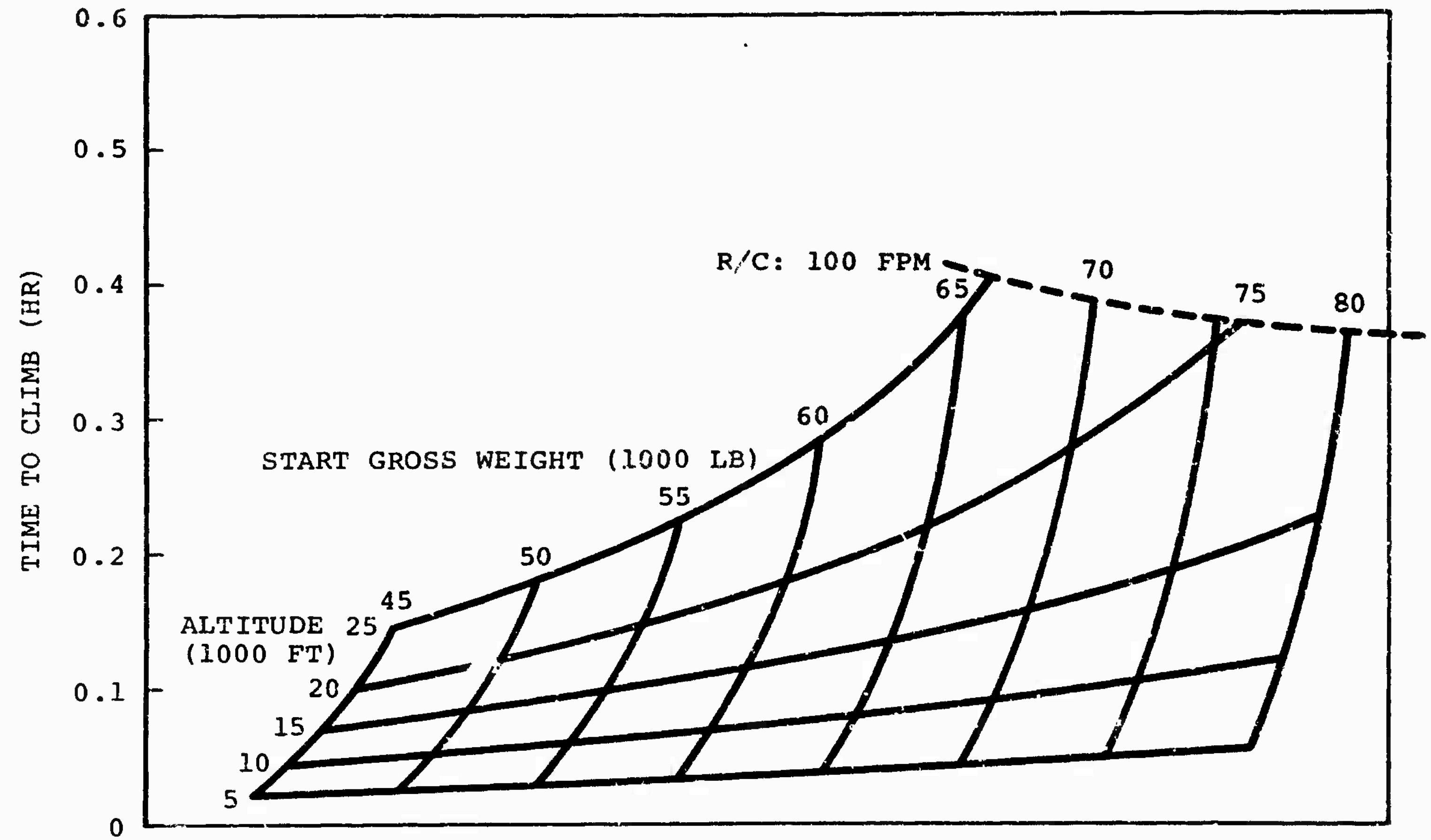


Figure 149. Design Point I Time to Climb From Sea Level at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

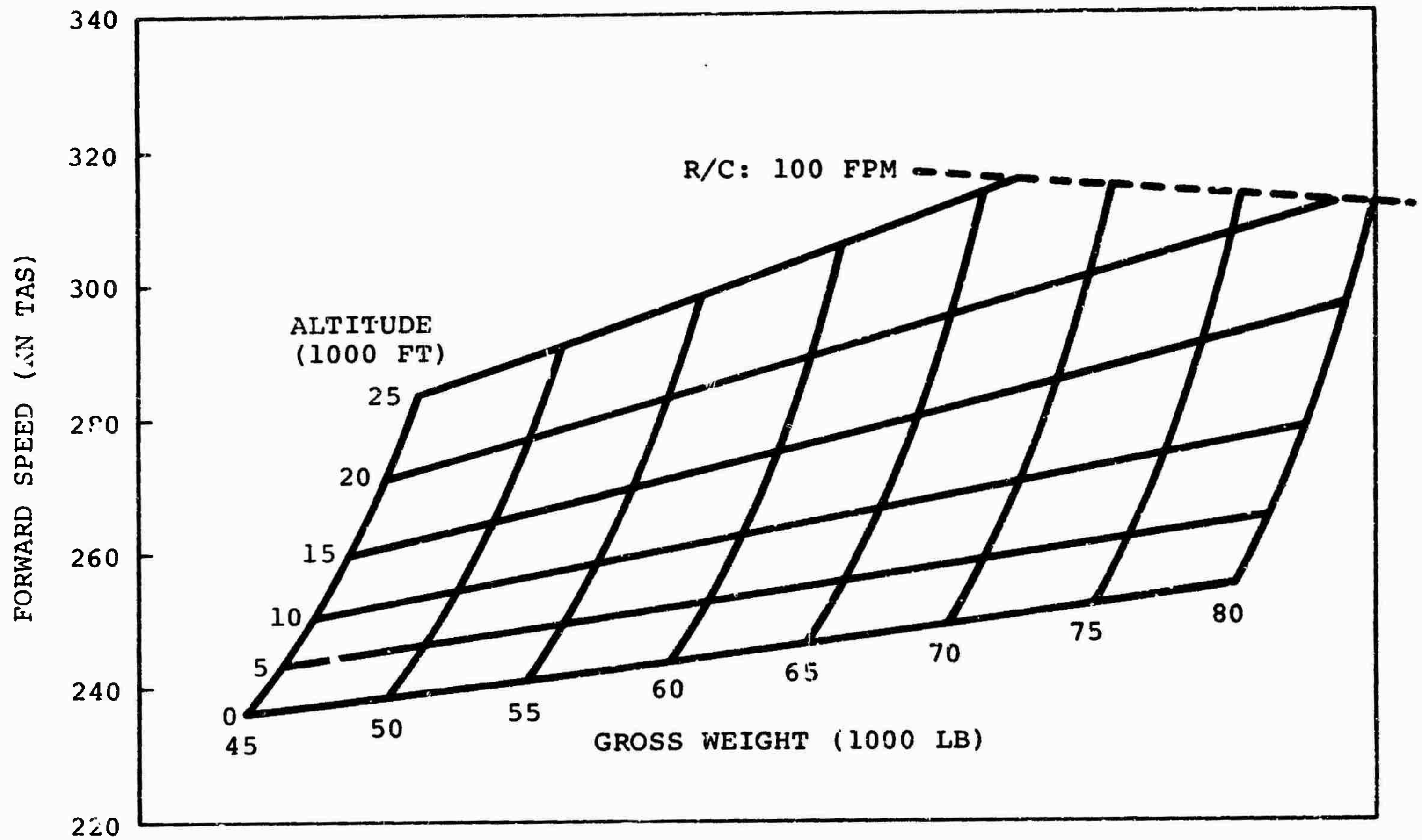


Figure 150. Design Point I Forward Speed at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

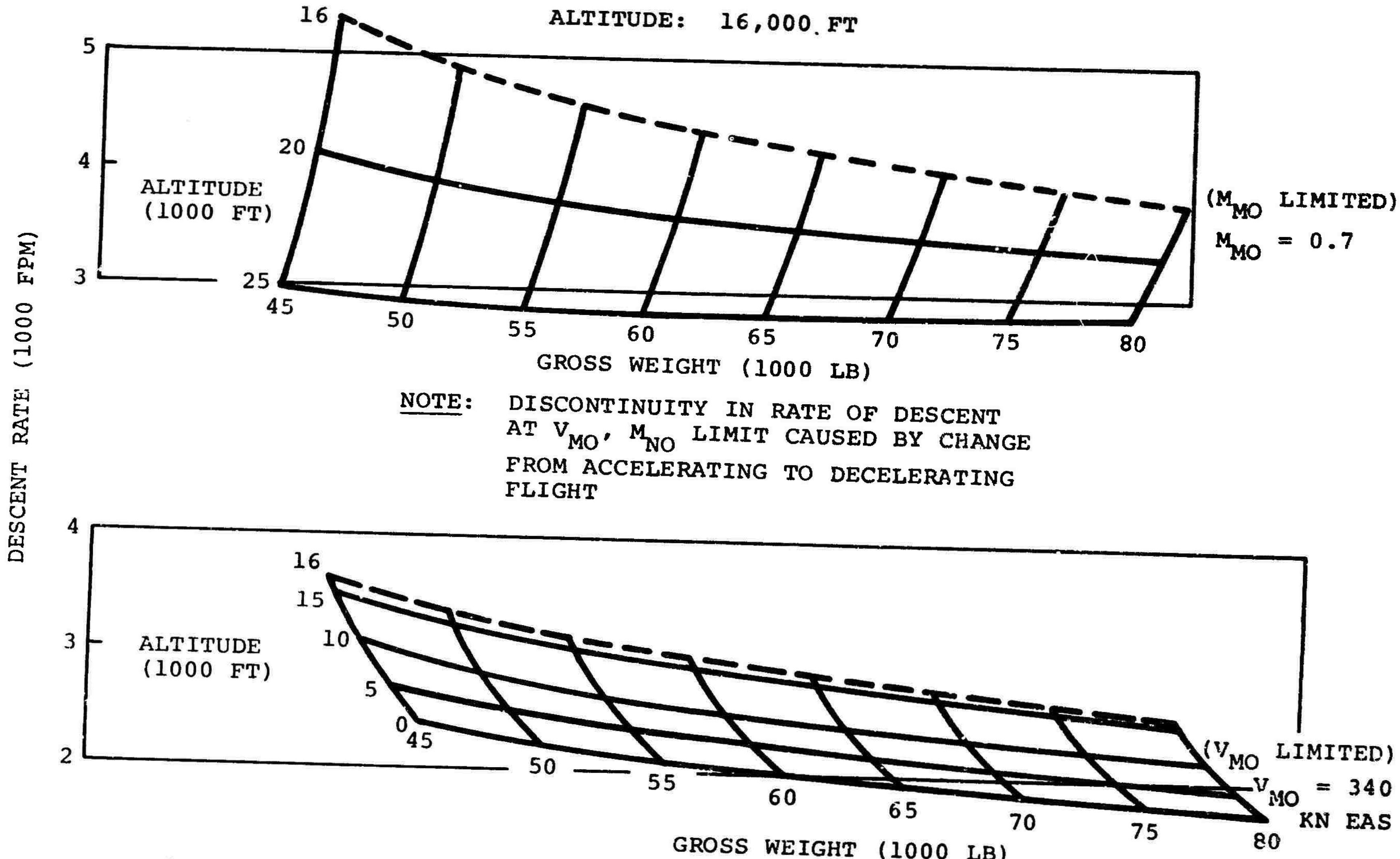


Figure 151. Design Point I Maximum Rate of Descent fo Standard Day With All Engines Operating at Flight Idle Power.

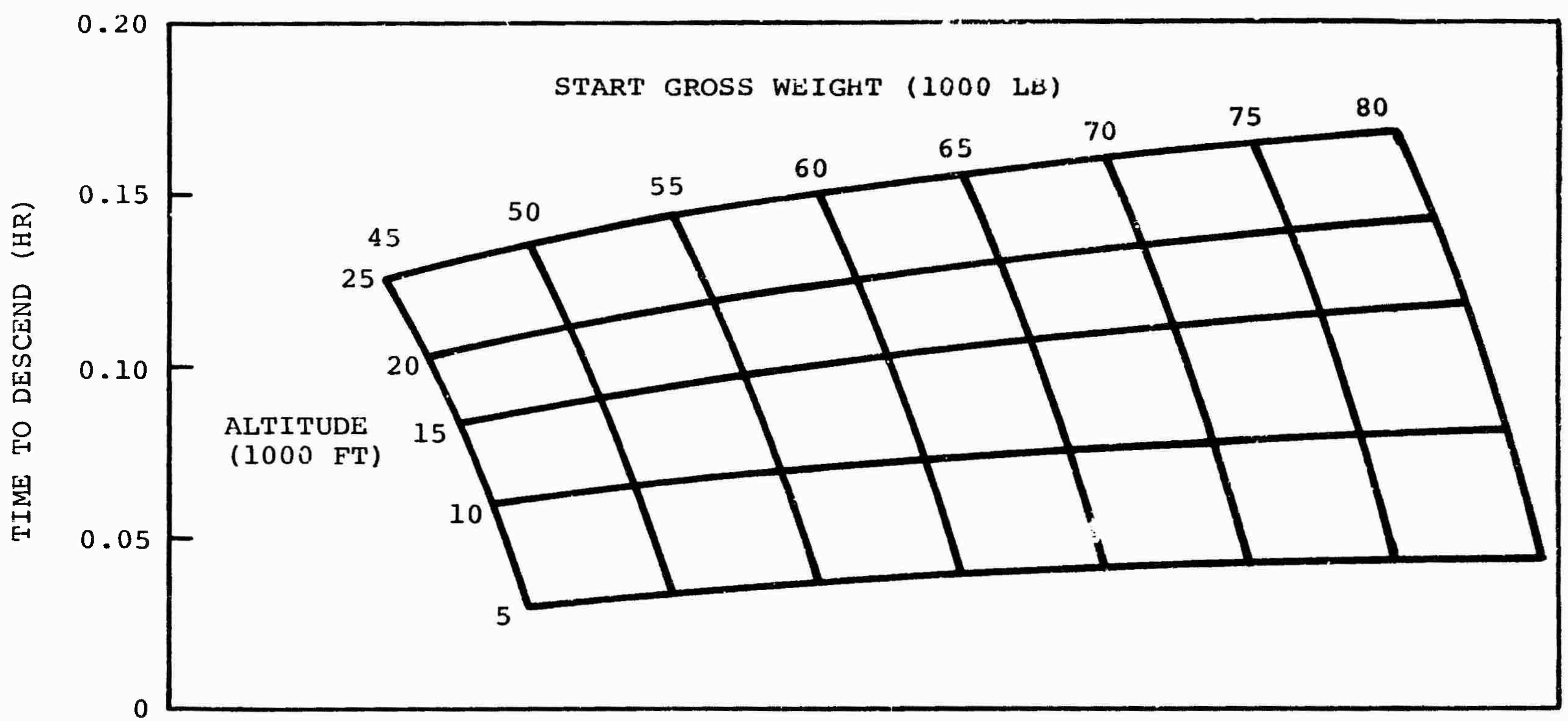


Figure 152. Design Point I Time to Descend to Sea Level at Maximum Rate of Descent for Standard Day With All Engines Operating at Flight Idle Power.

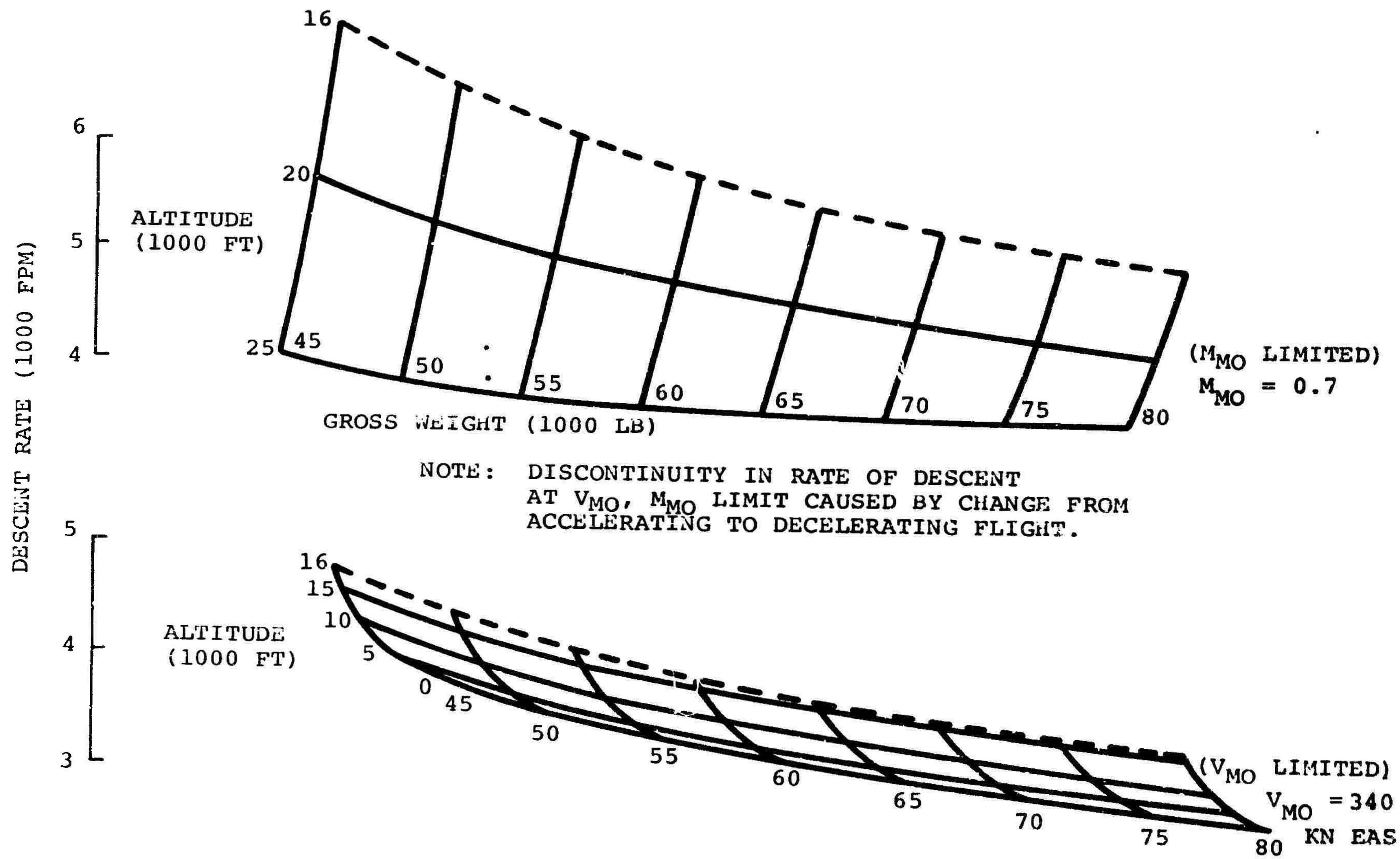


Figure 153. Design Point I Maximum Rate of Descent for Air Force Hot Day With All Engines Operating at Flight Idle Power.

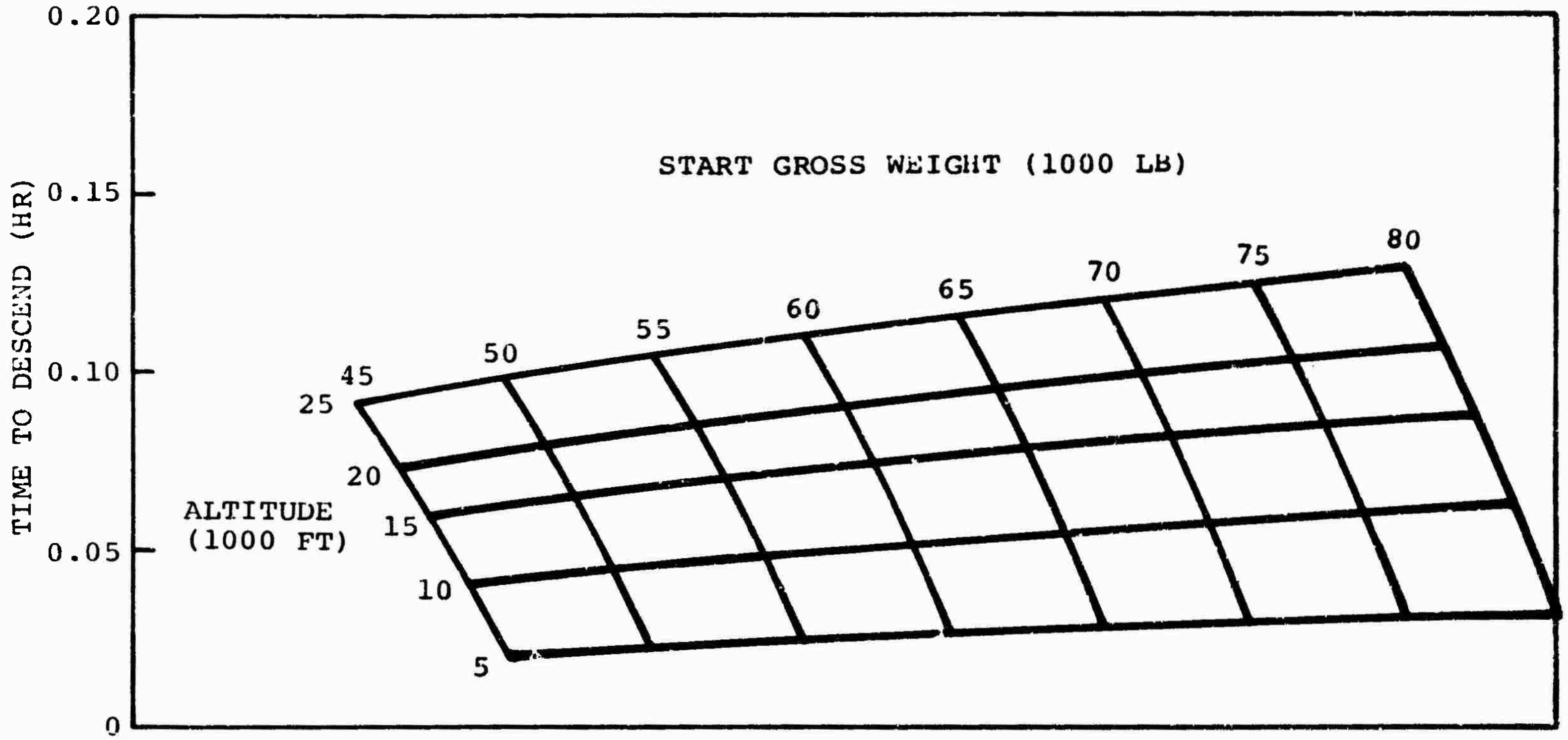


Figure 154. Design Point I Time to Descend to Sea Level at Maximum Rate of Descent for Air Force Hot Day With All Engines Operating at Flight Idle Power.

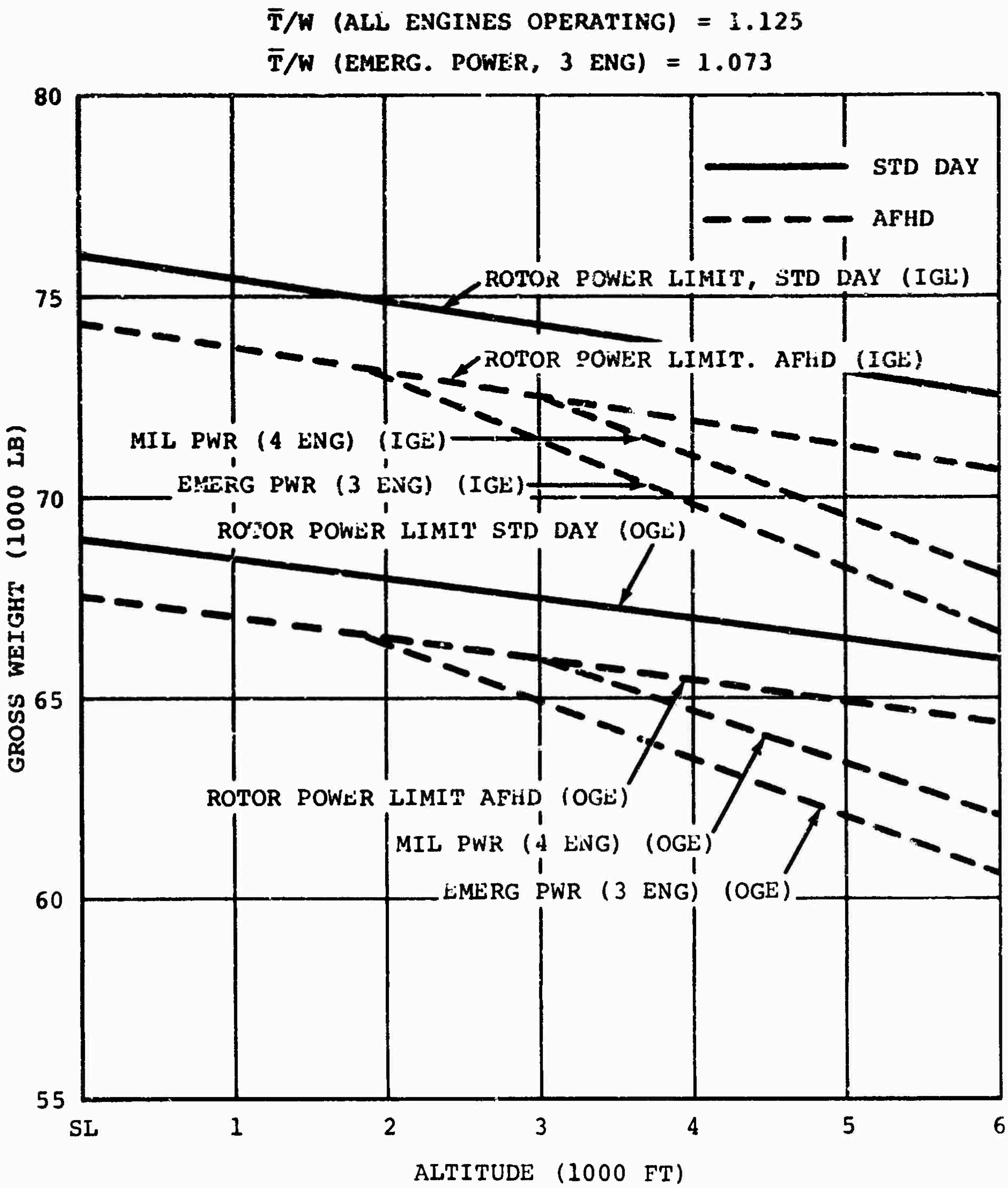


Figure 155. Design Point I Gross Weight Hover Capability Versus Altitude for Air Force Hot Day and Standard Day Conditions.

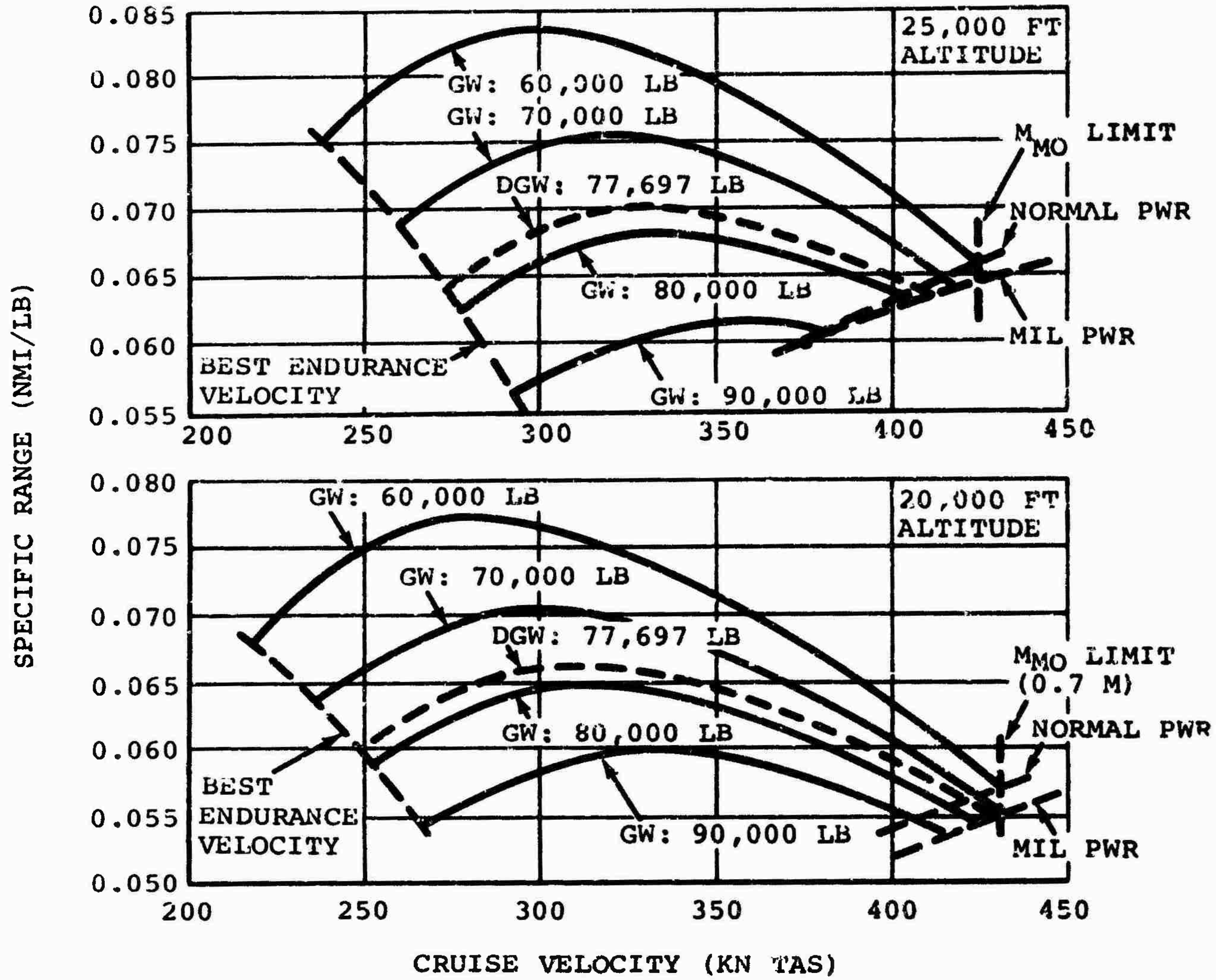


Figure 156. Design Point II Standard Day Cruise Performance (Sheet 1 of 3).

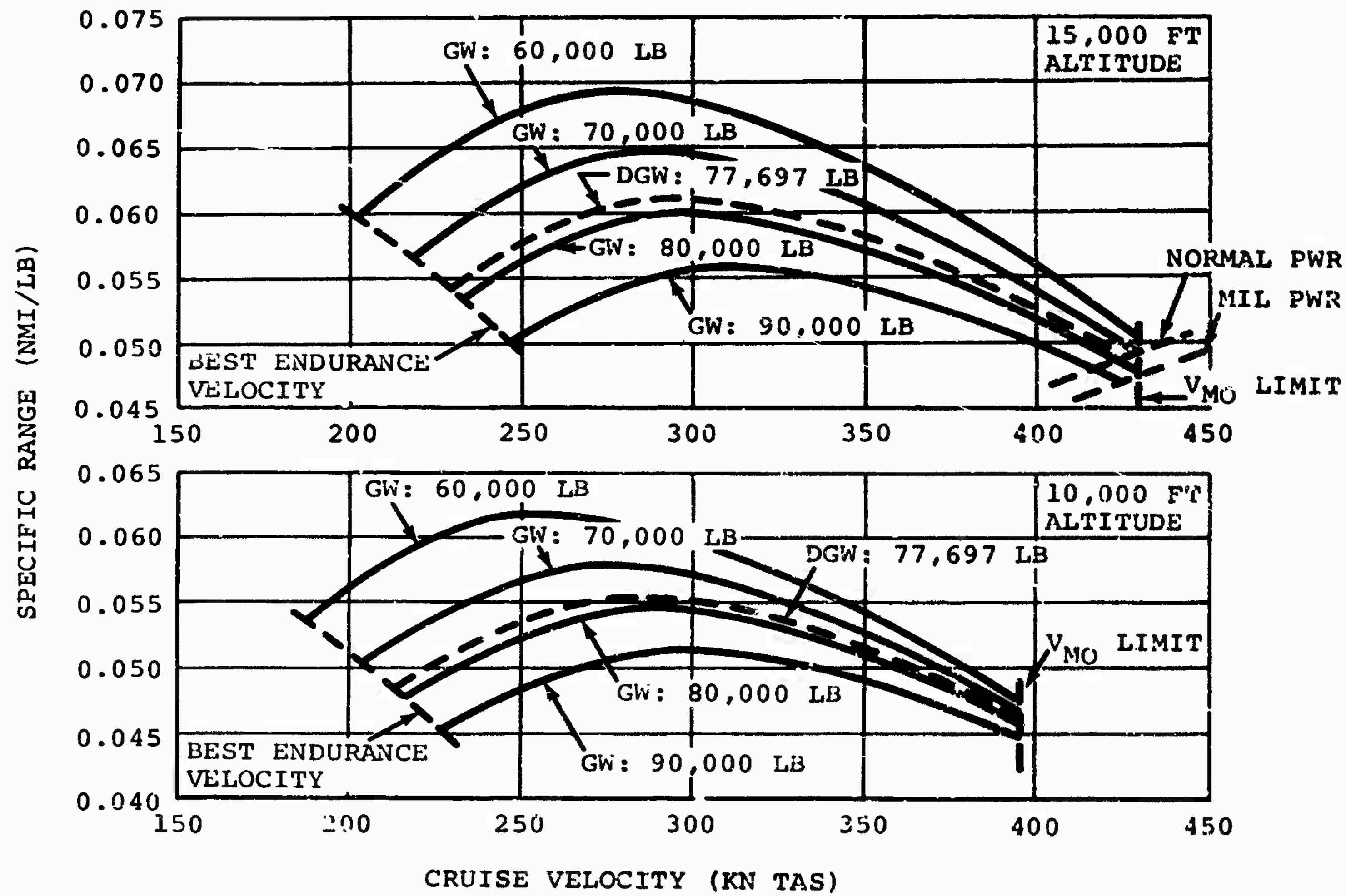


Figure 156. Design Point II Standard Day Cruise Performance (Sheet 2 of 3).

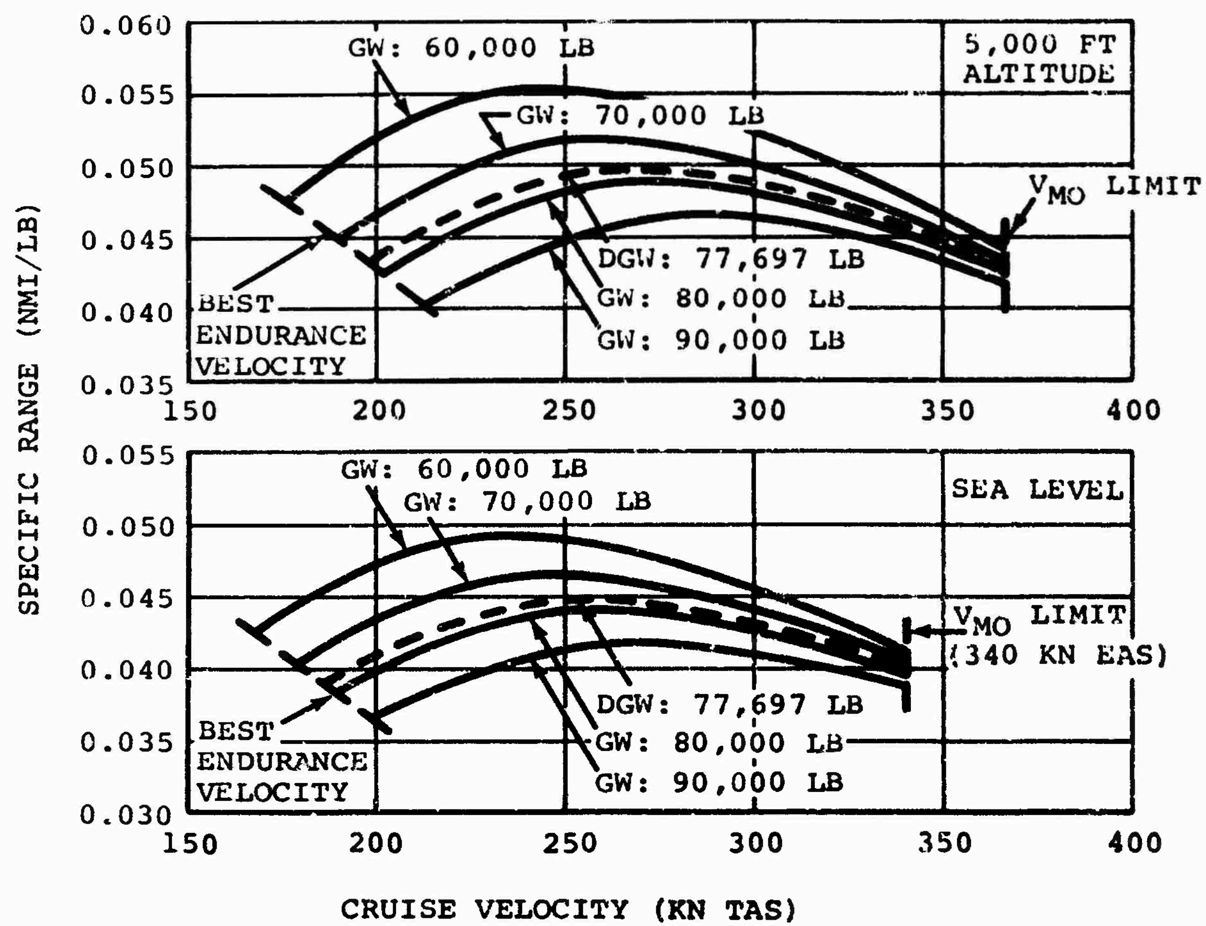


Figure 156. Design Point II Standard Day Cruise Performance (Sheet 3 of 3).

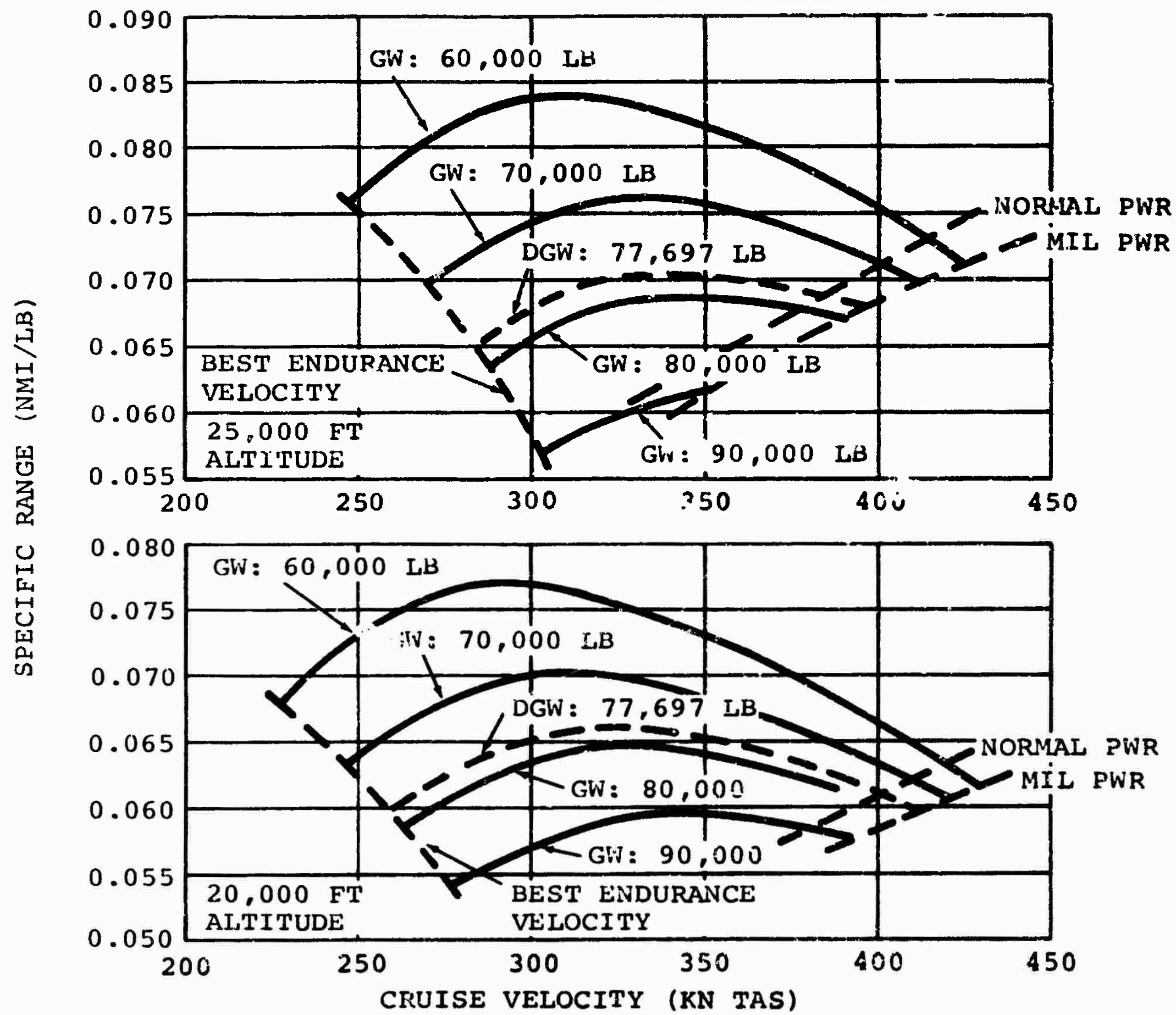


Figure 157. Design Point II Cruise Performance for Air Force Hot Day (Sheet 1 of 3).

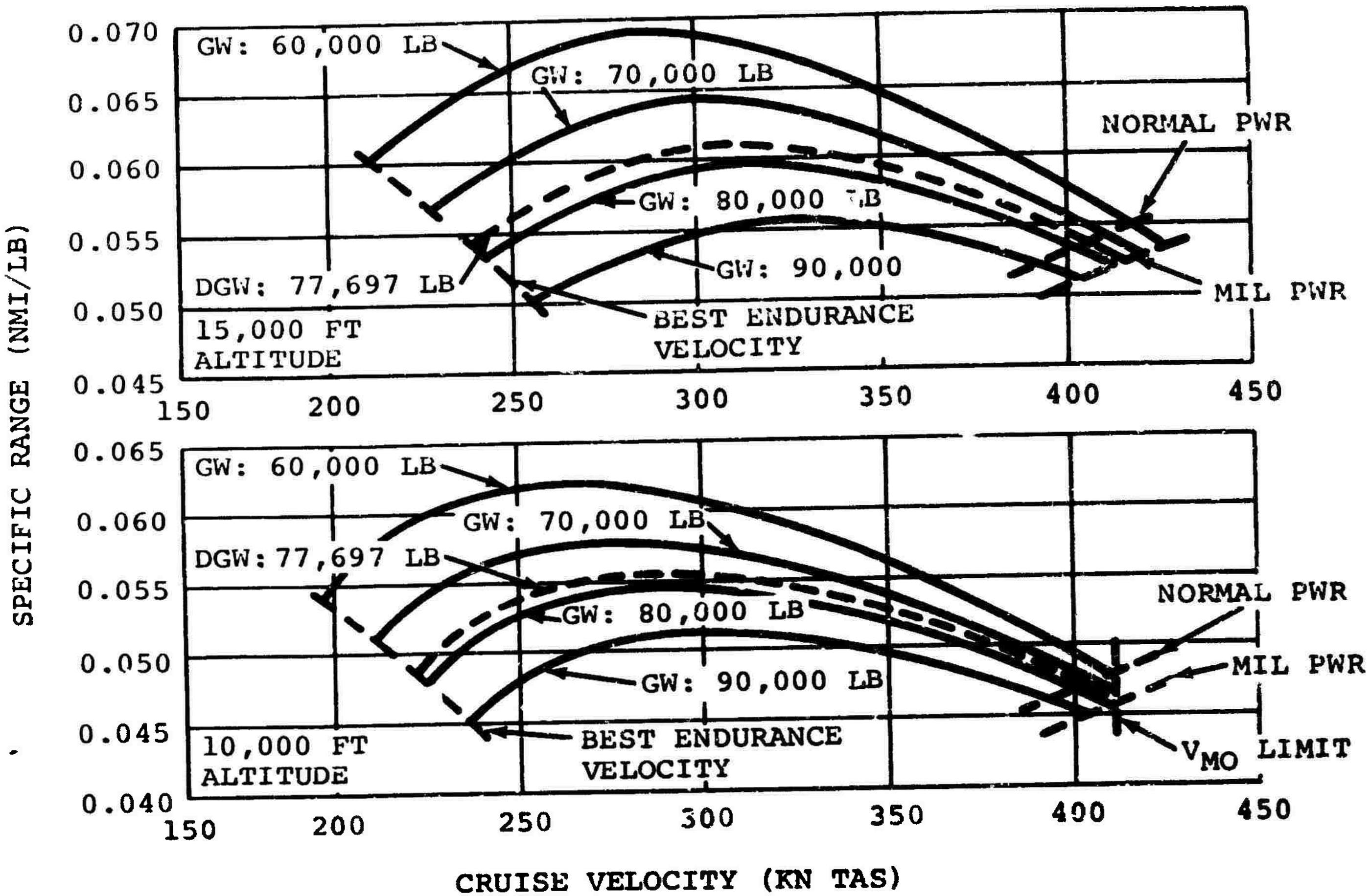


Figure 157. Design Point II Cruise Performance for Air Force Hot Day (Sheet 2 of 3).

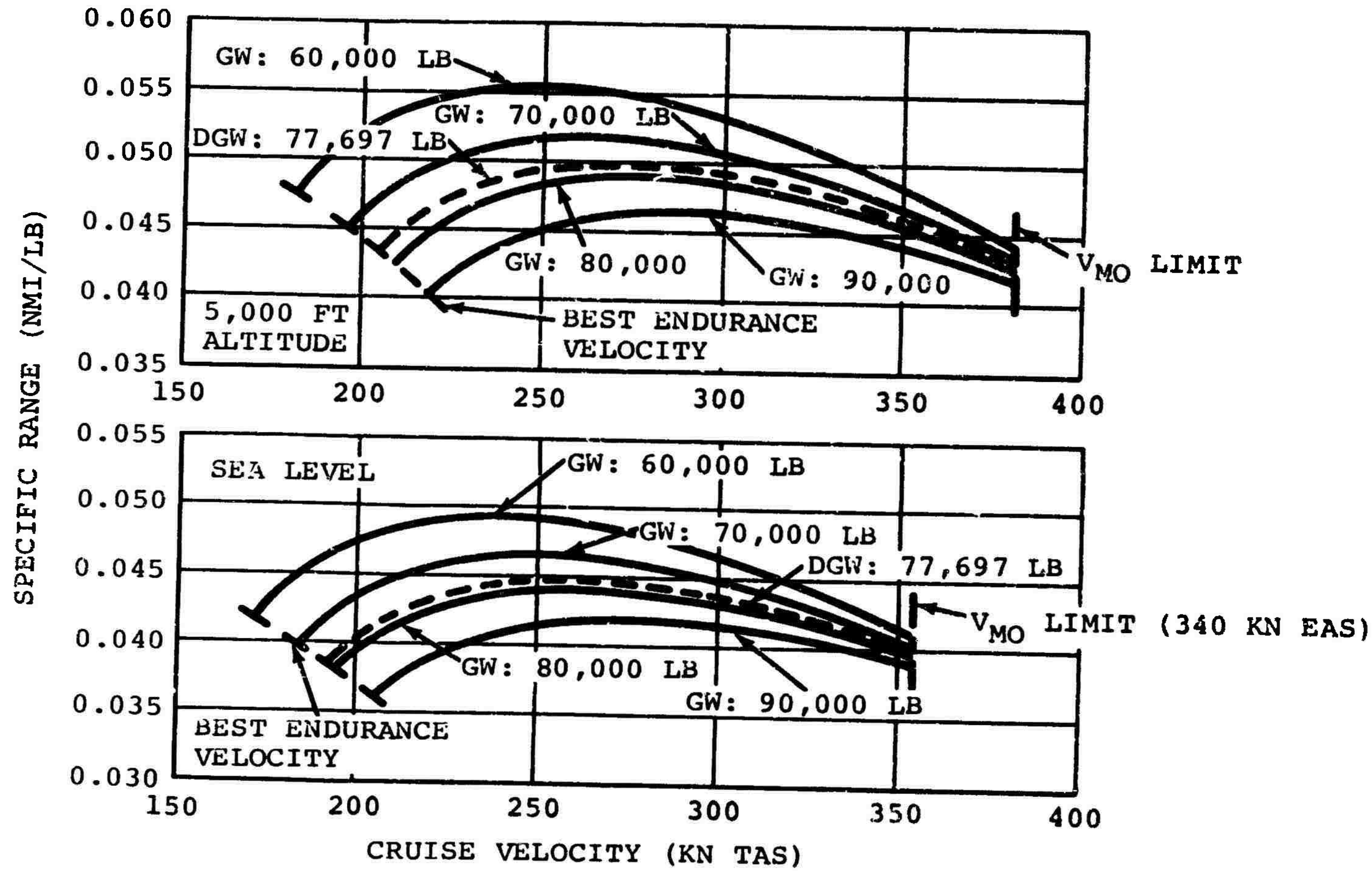


Figure 157. Design Point II Cruise Performance for Air Force Hot Day (Sheet 3 of 3).

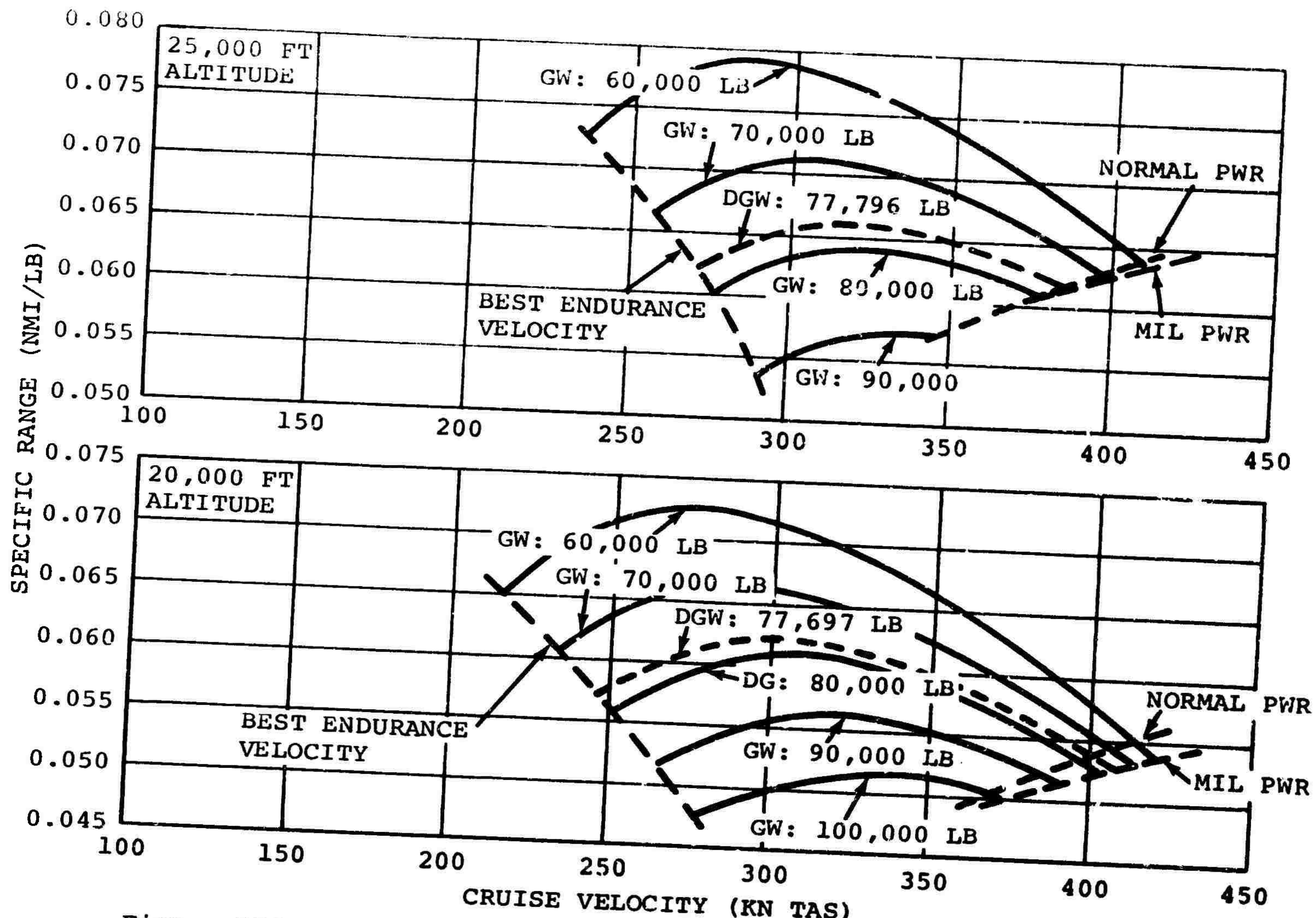


Figure 158. Design Point II Cruise Performance (With Capsule) for Standard Day (Sheet 1 of 3).

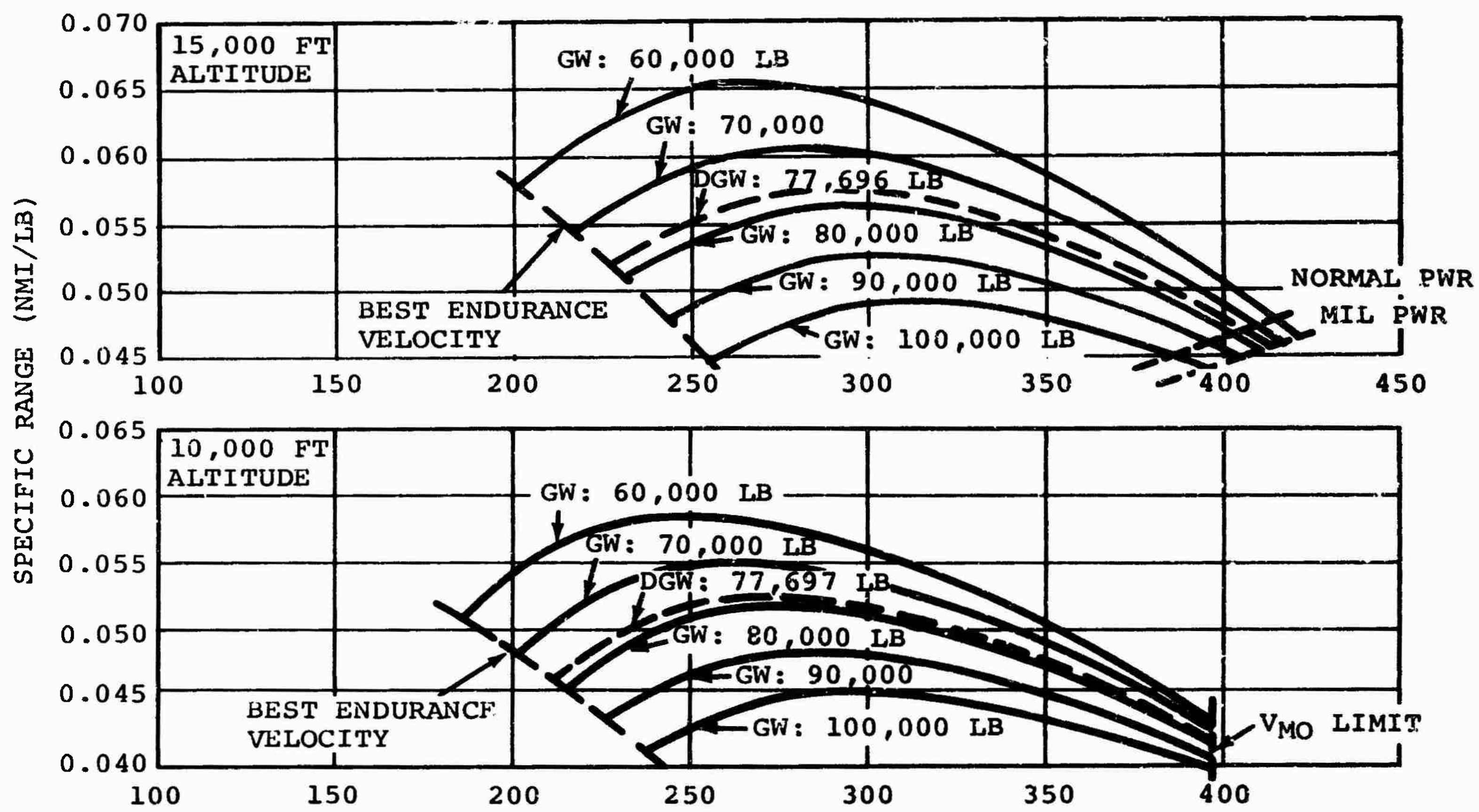


Figure 158. Design Point II Cruise Performance (With Capsule) for Standard Day (Sheet 2 of 3).

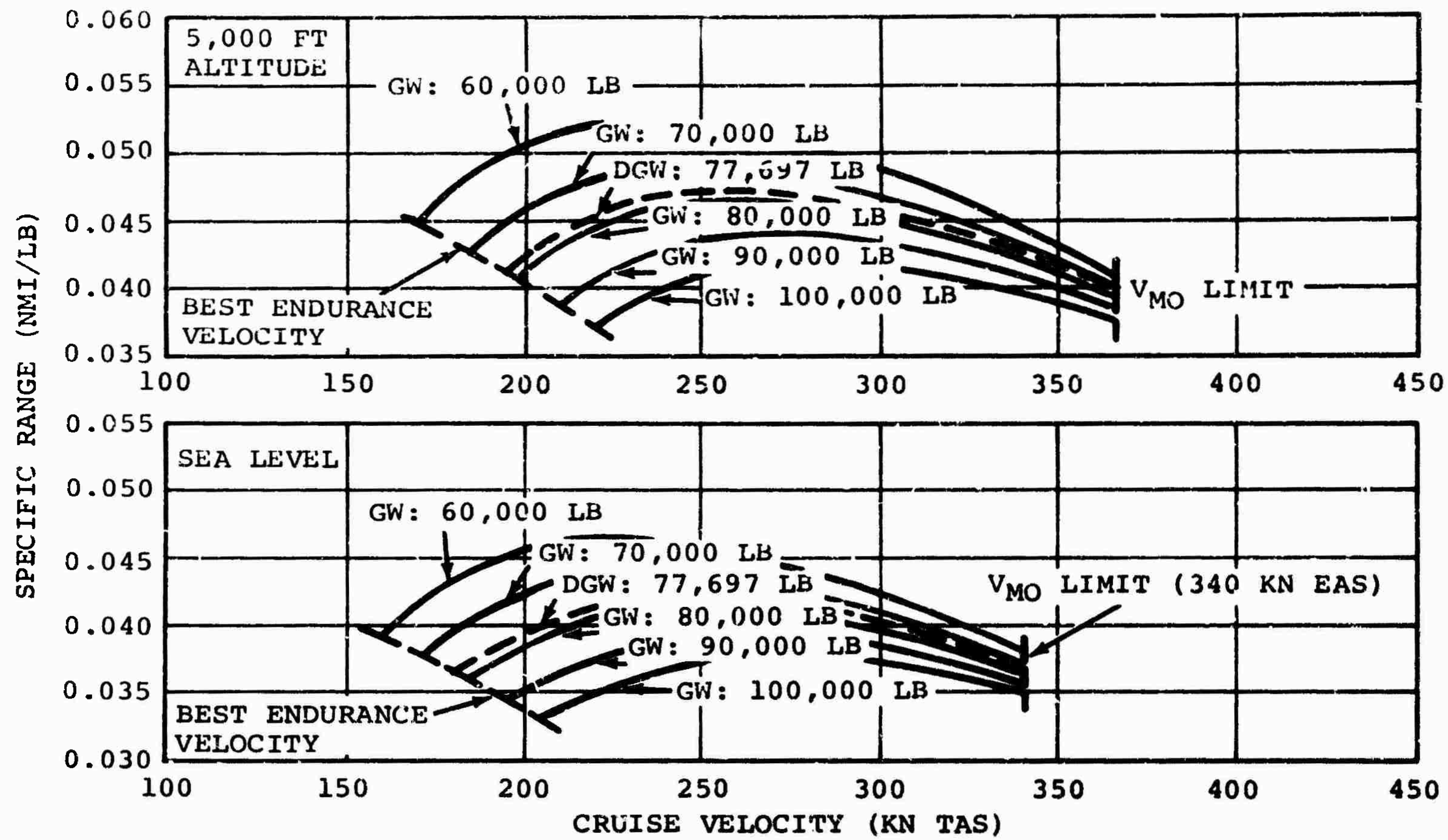


Figure 158. Design Point II Cruise Performance (With Capsule) for Standard Day (Sheet 3 of 3).

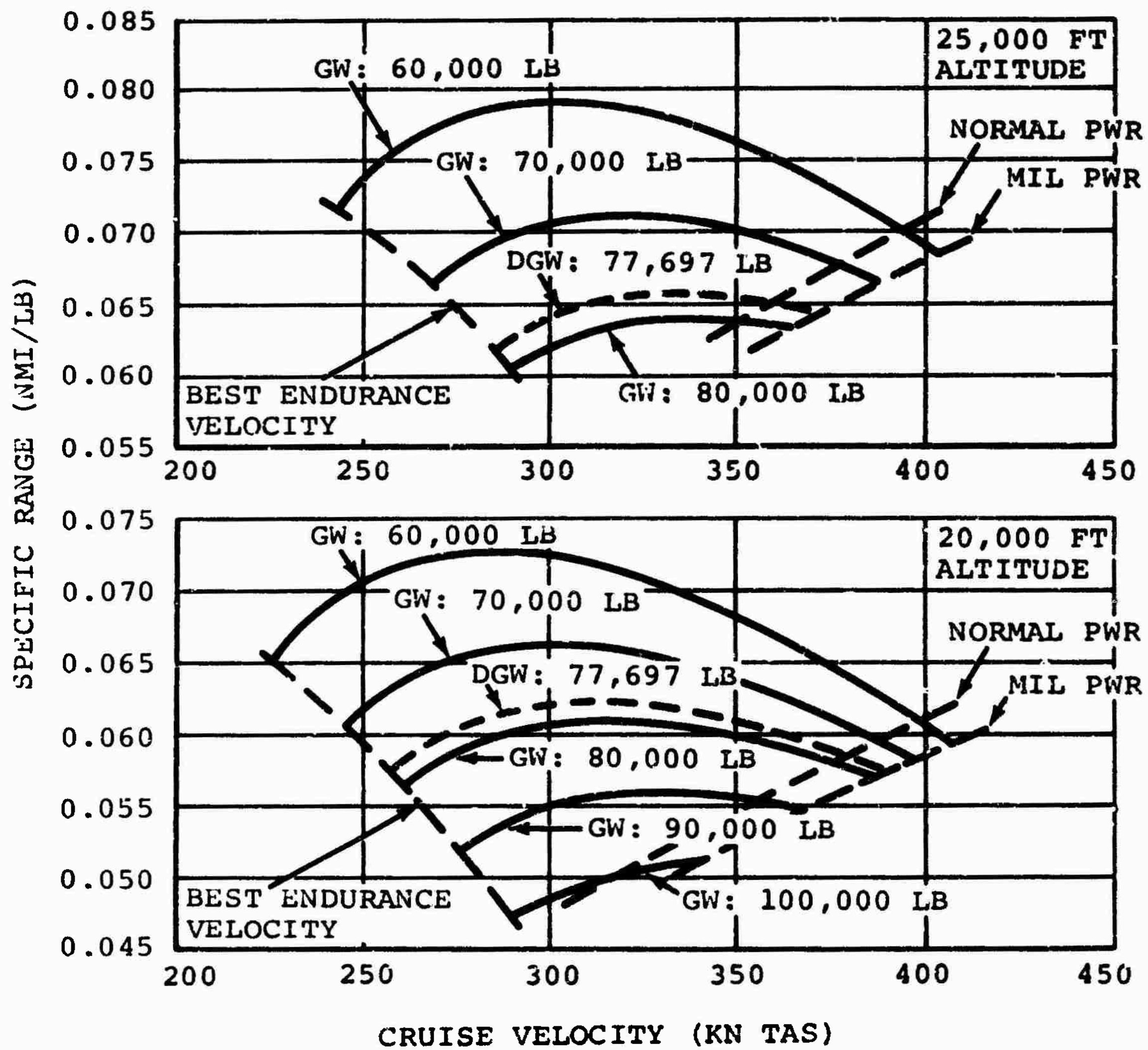


Figure 159. Design Point II Cruise Performance (With Capsule) for Air Force Hot Day (Sheet 1 of 3).

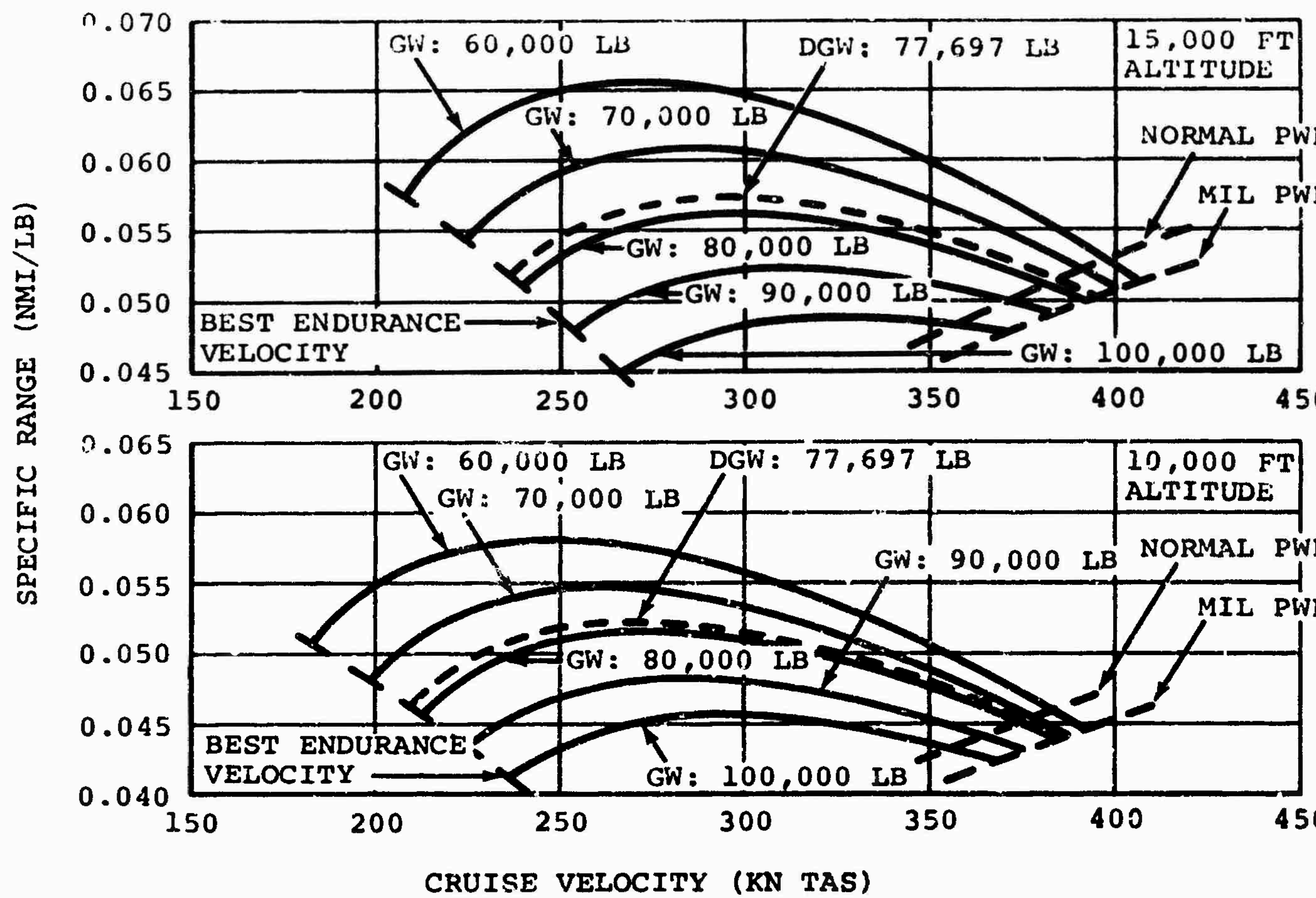


Figure 159. Design Point II Cruise Performance (With Capsule) for Air Force Hot Day (Sheet 2 of 3).

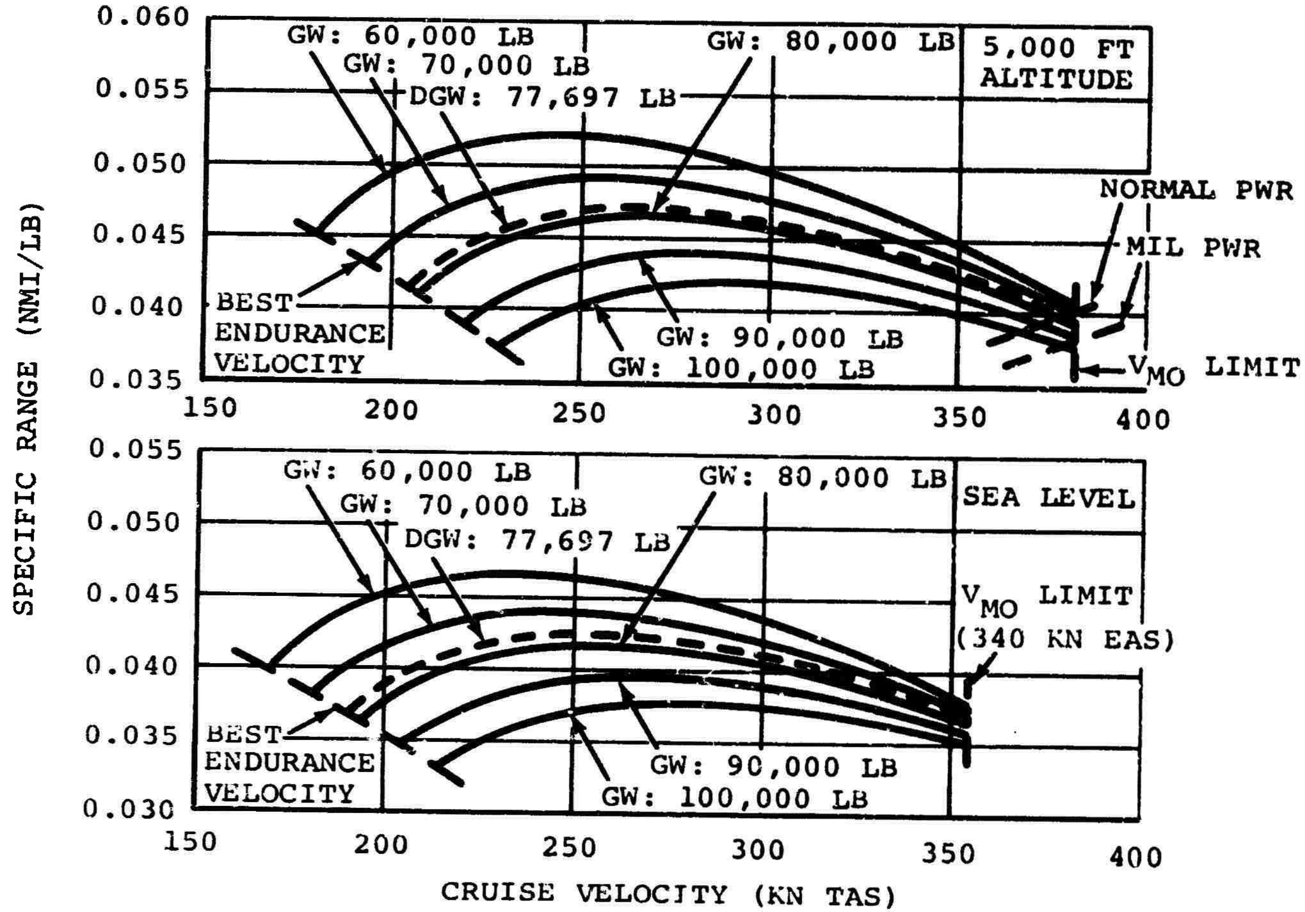


Figure 159. Design Point II Cruise Performance (With Capsule) for Air Force Hot Day (Sheet 3 of 3).

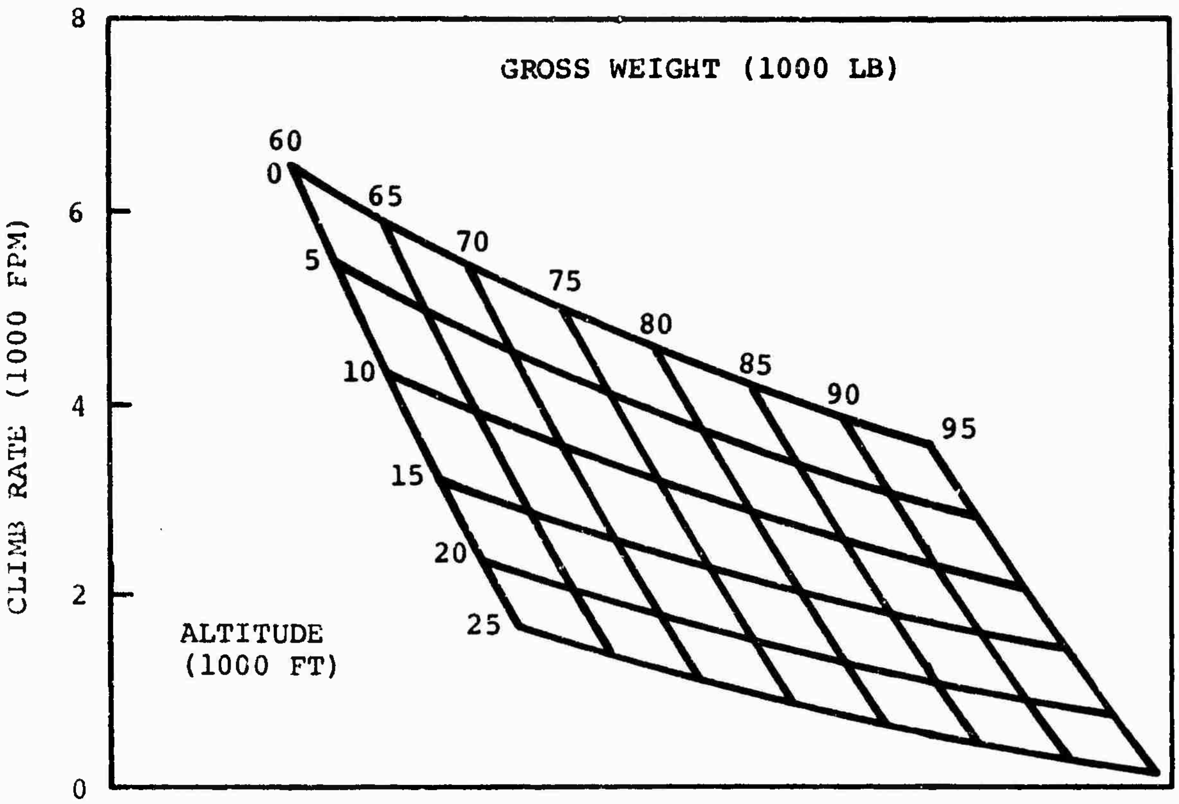


Figure 160. Design Point II Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

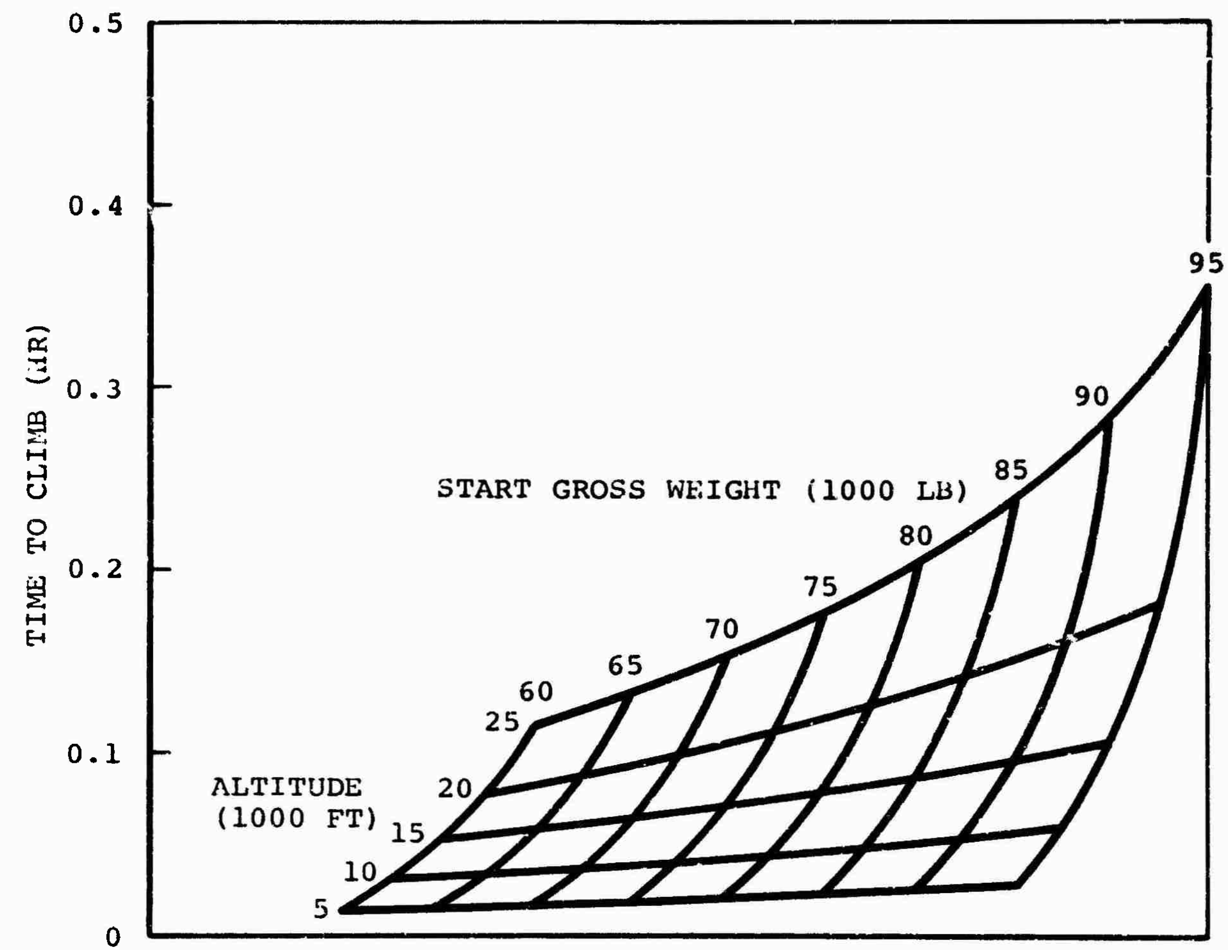


Figure 161. Design Point II Time to Climb From Sea Level at Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

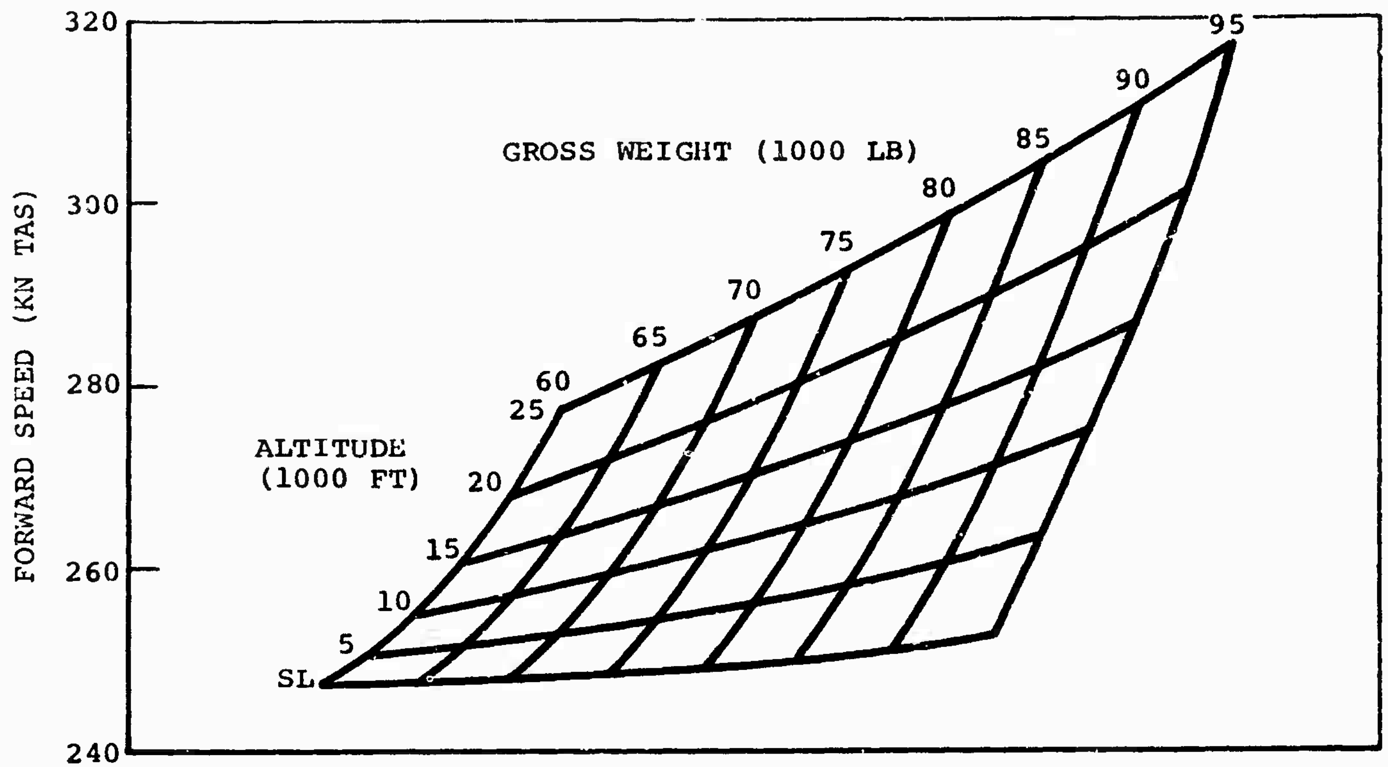


Figure 162. Design Point II Forward Speed at Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

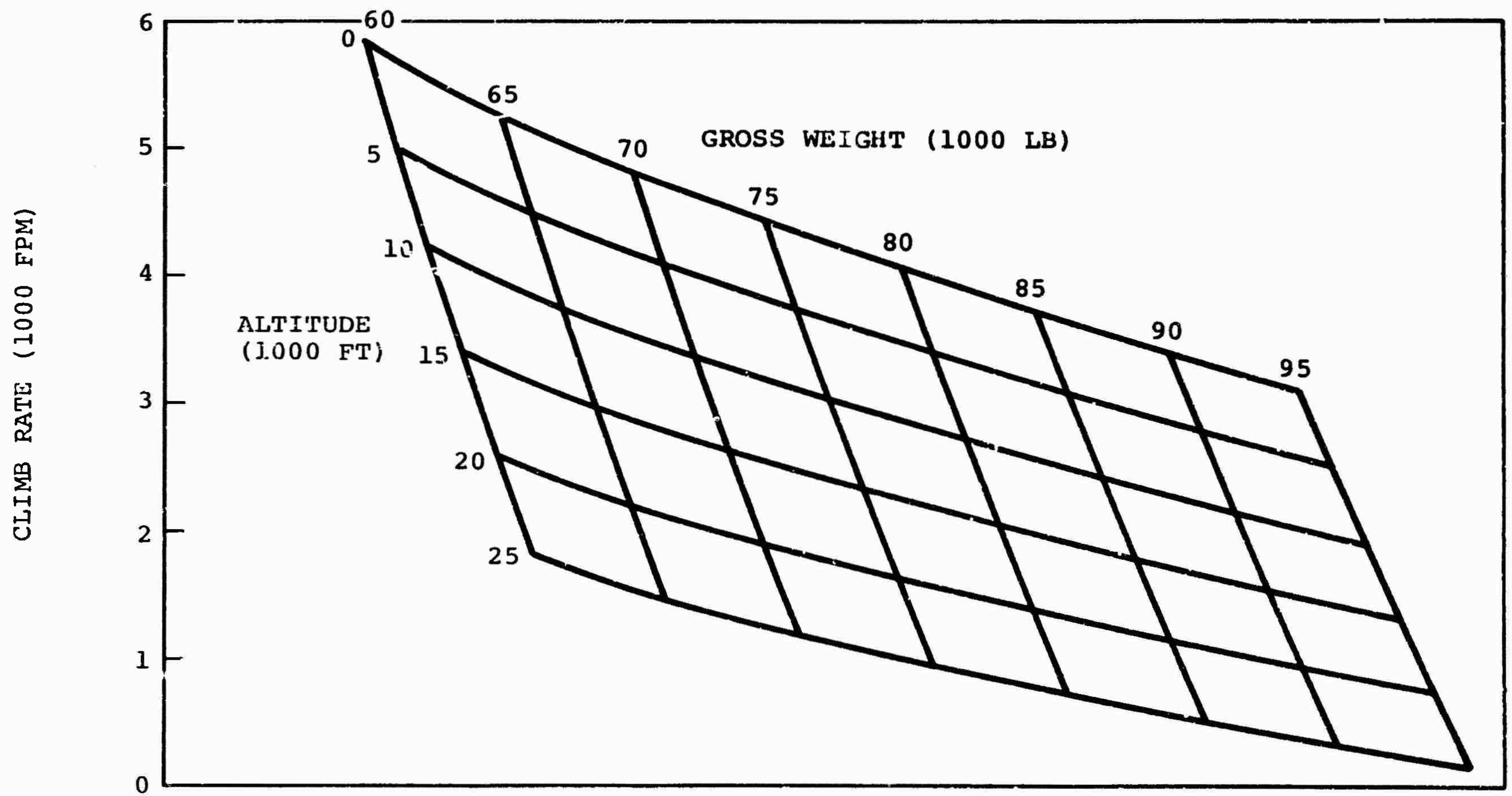


Figure 163. Design Point II Maximum Rate of Climb for Standard Day With All Engines Operating at Military Power.

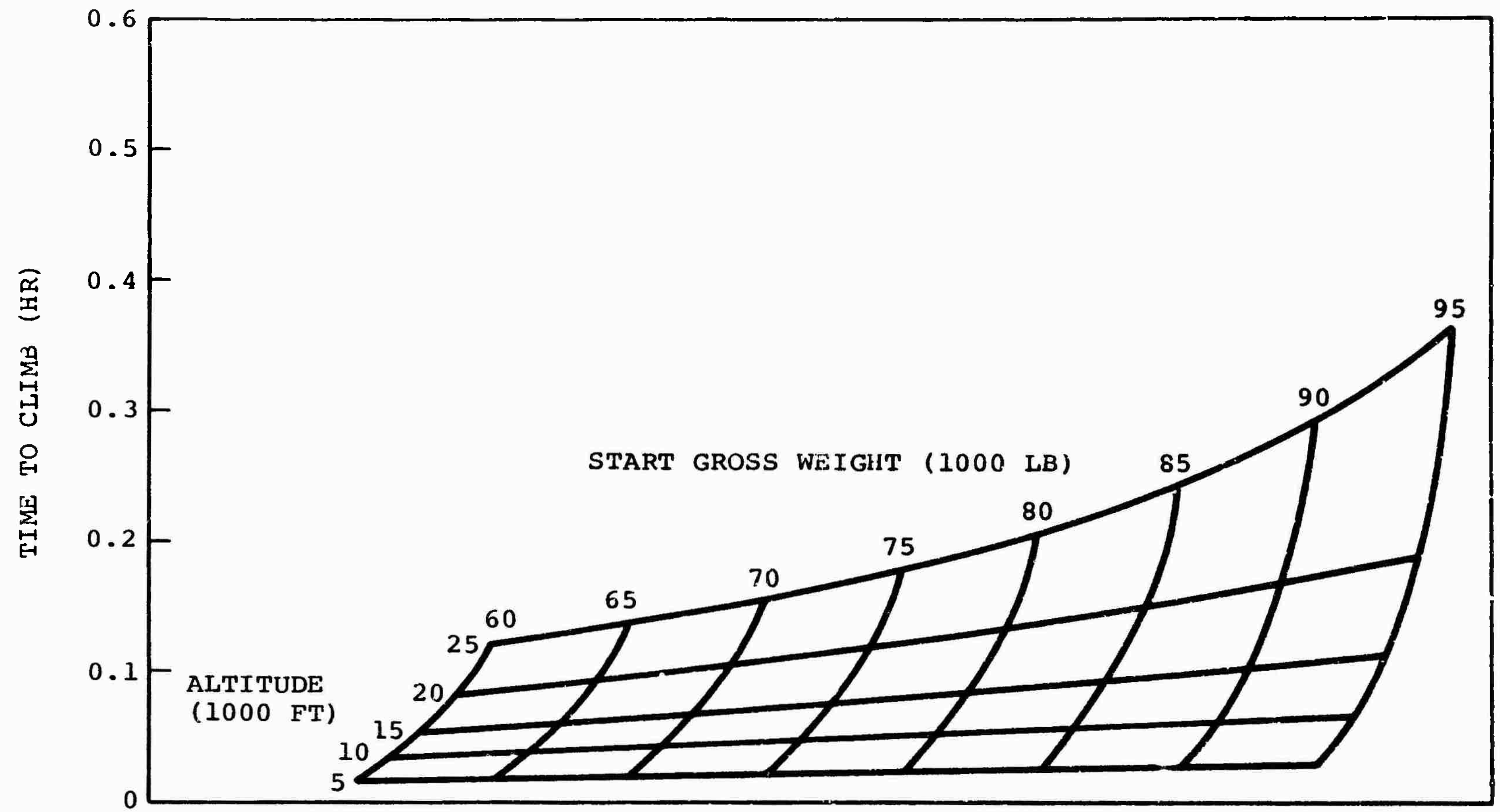


Figure 164. Design Point II Time to Climb from Sea Level at Maximum Rate of Climb for Standard Day With All Engines Operating at Military Power.

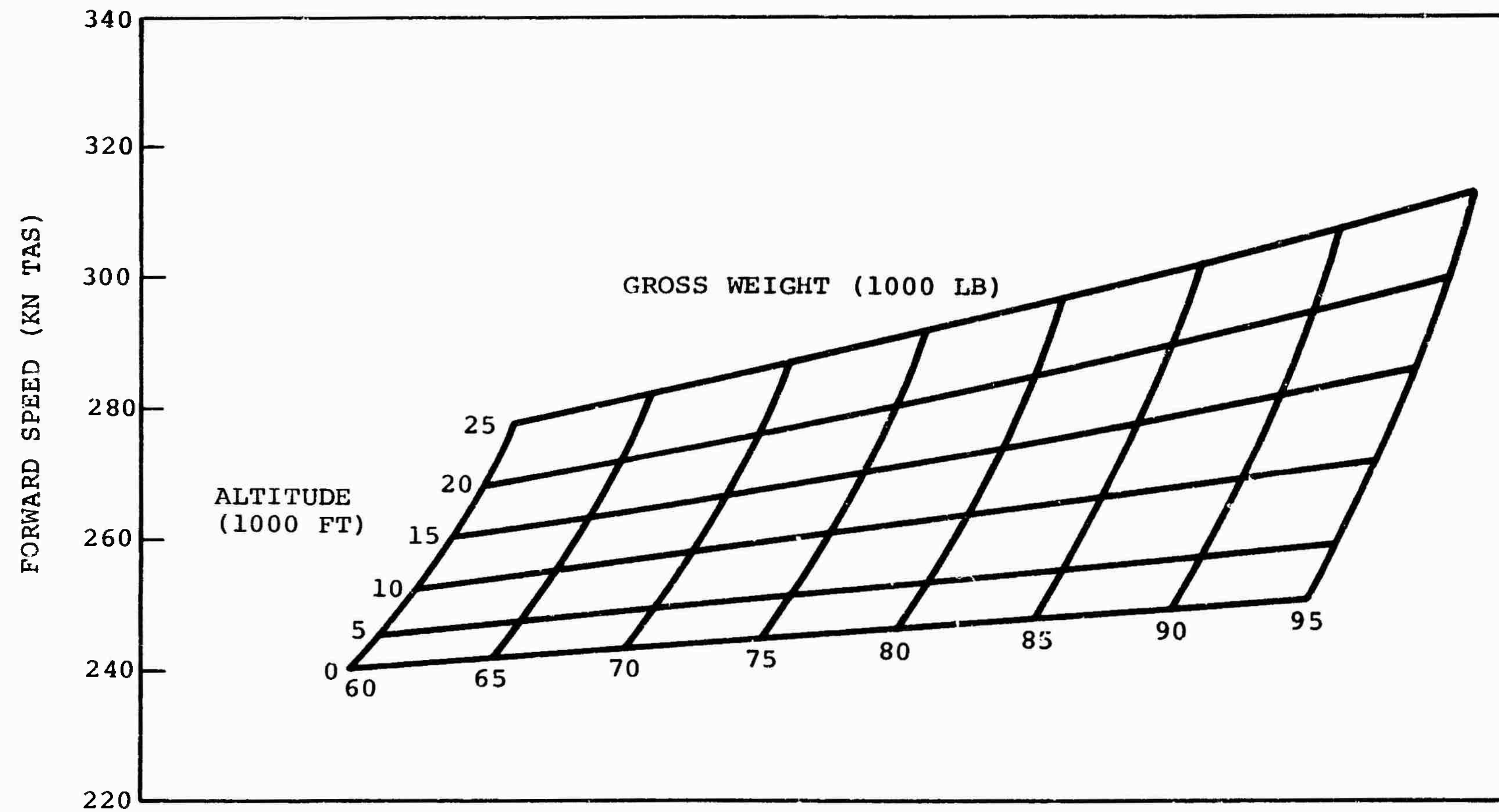


Figure 165. Design Point II Forward Speed at Maximum Rate of Climb for Standard Day With All Engines Operating at Military Power.

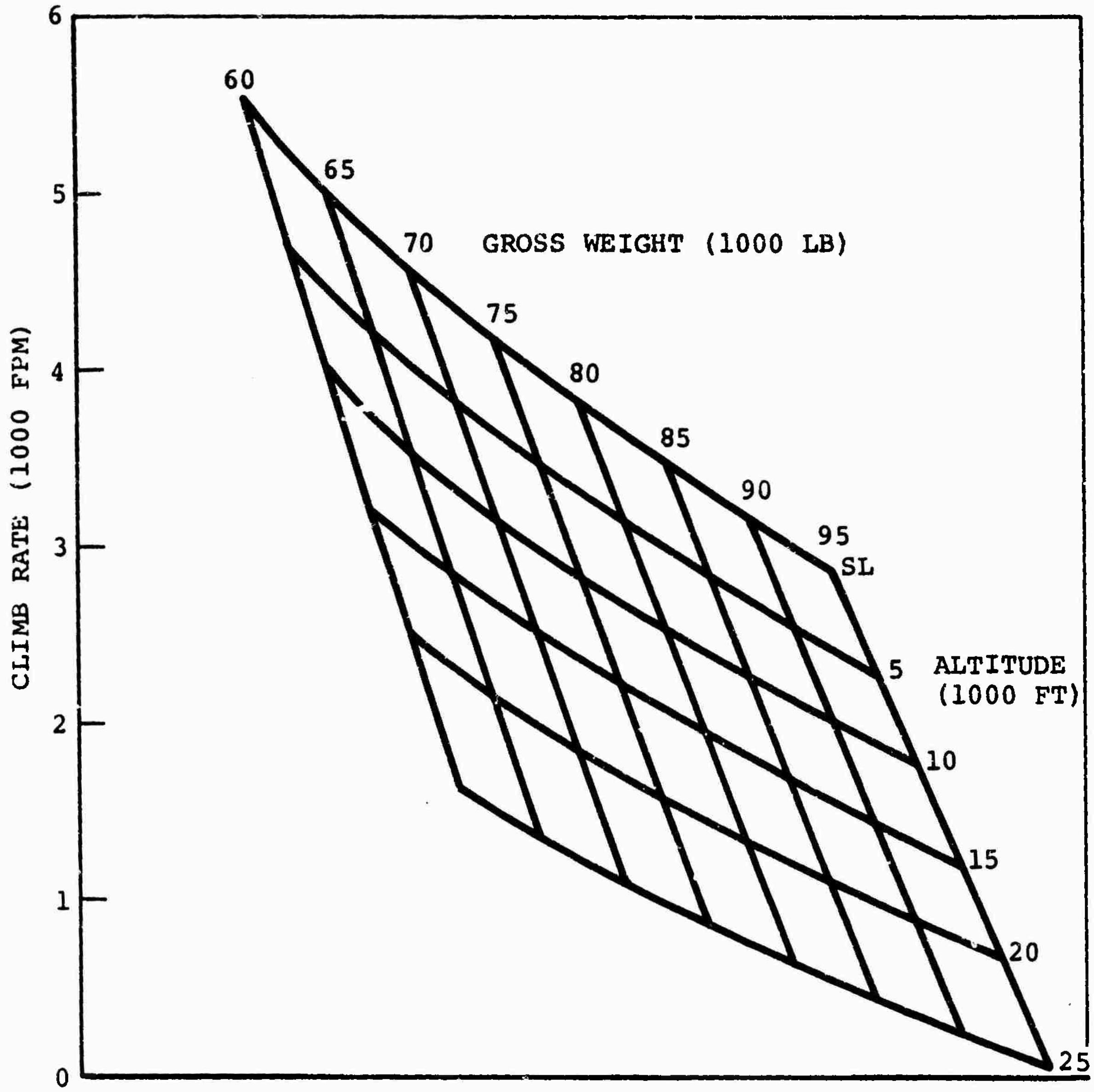


Figure 166. Design Point II Maximum Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.

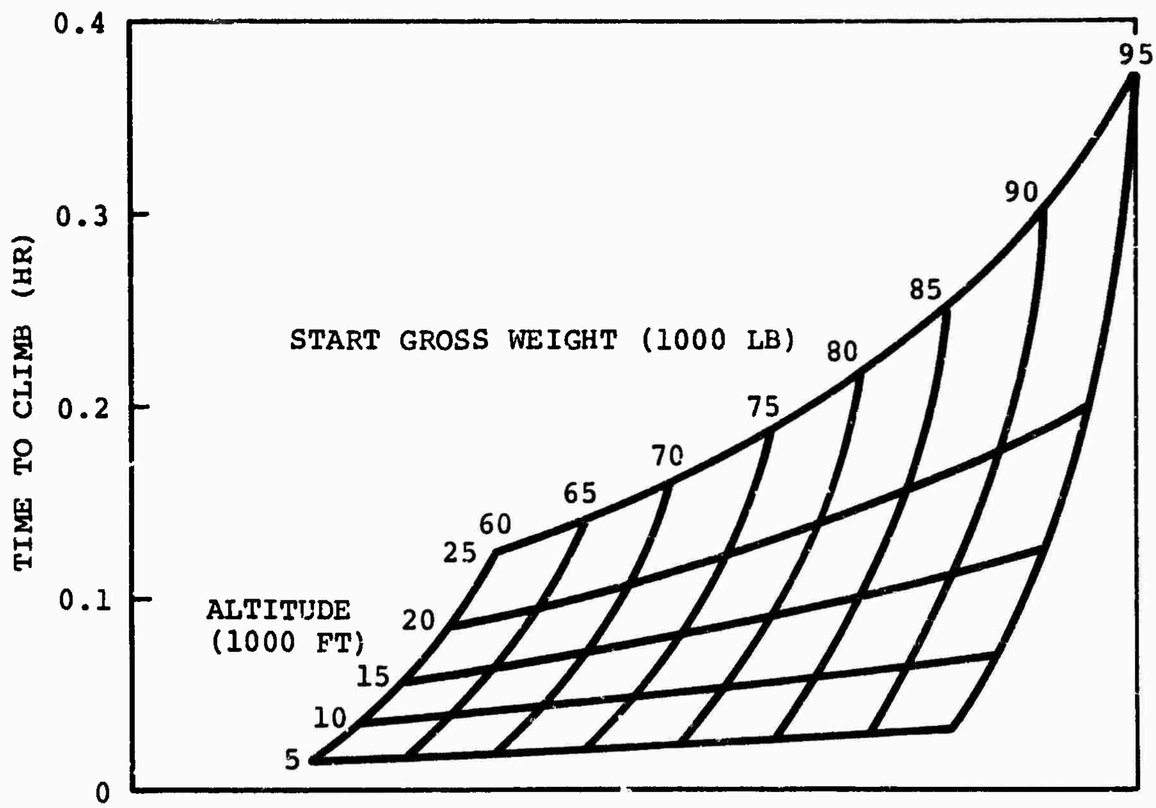


Figure 167. Des:gn Point II Time to Climb from Sea Level at Maximum Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.

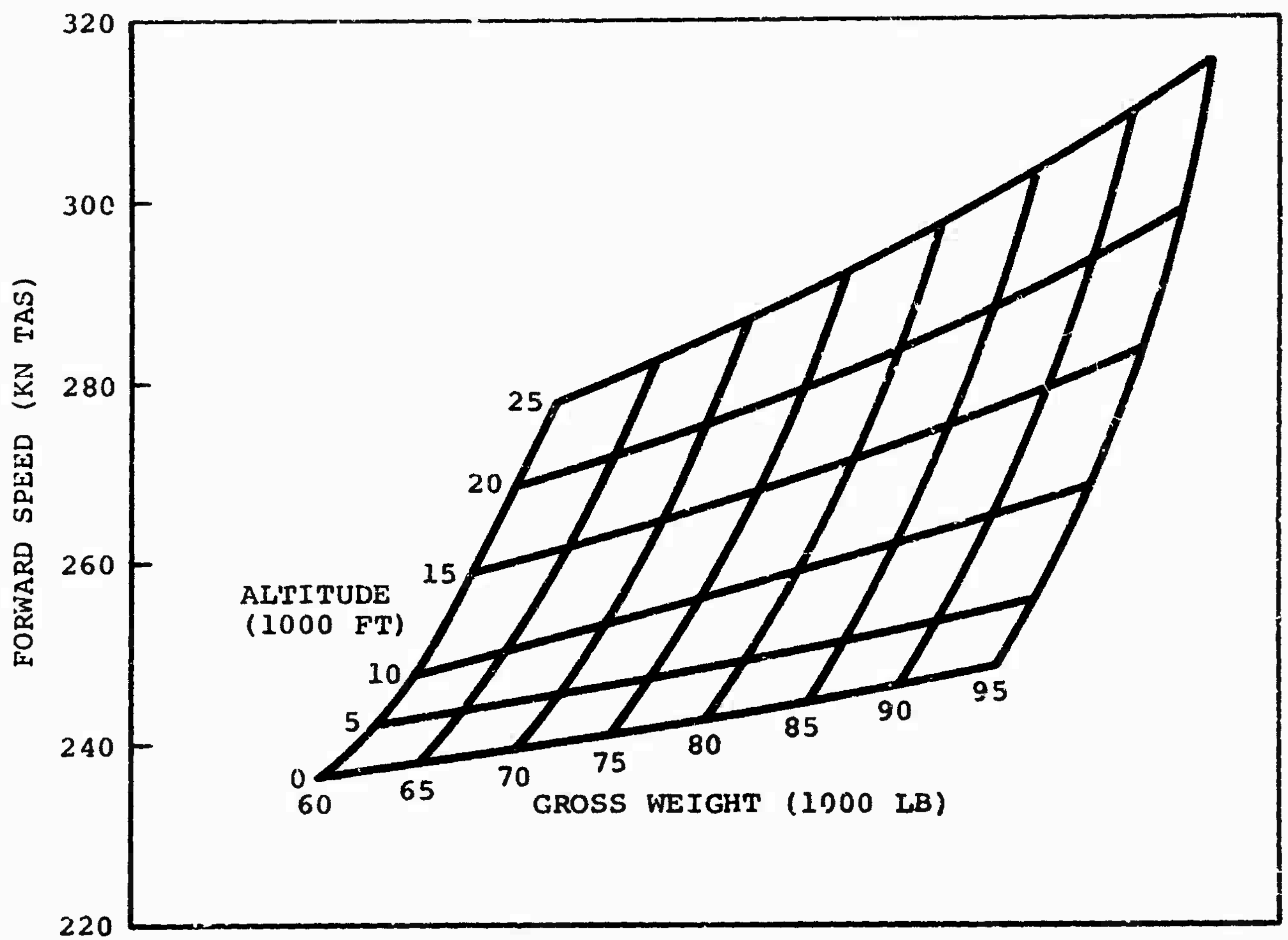


Figure 168. Design Point II Forward Speed at Maximum Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.

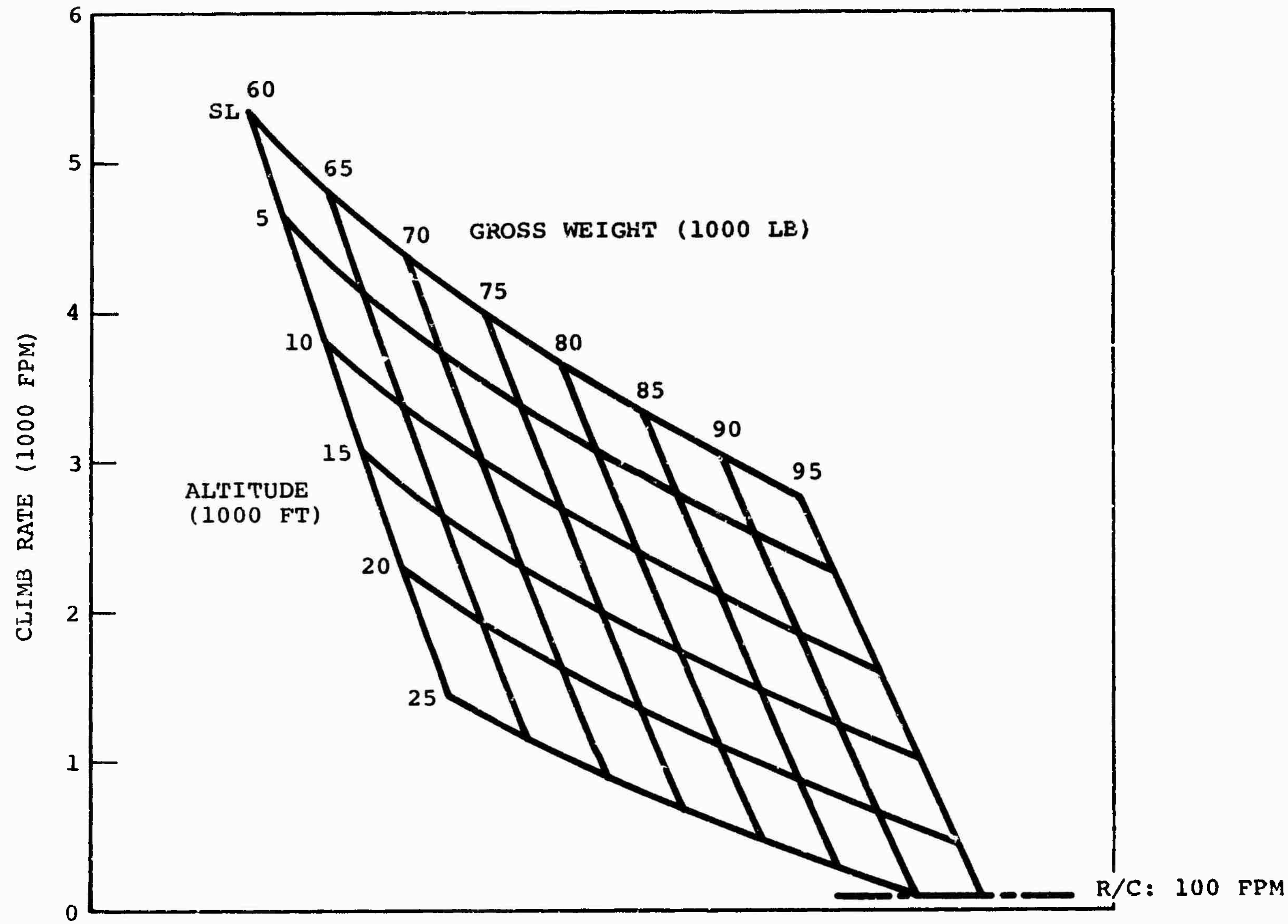


Figure 169. Design Point II Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

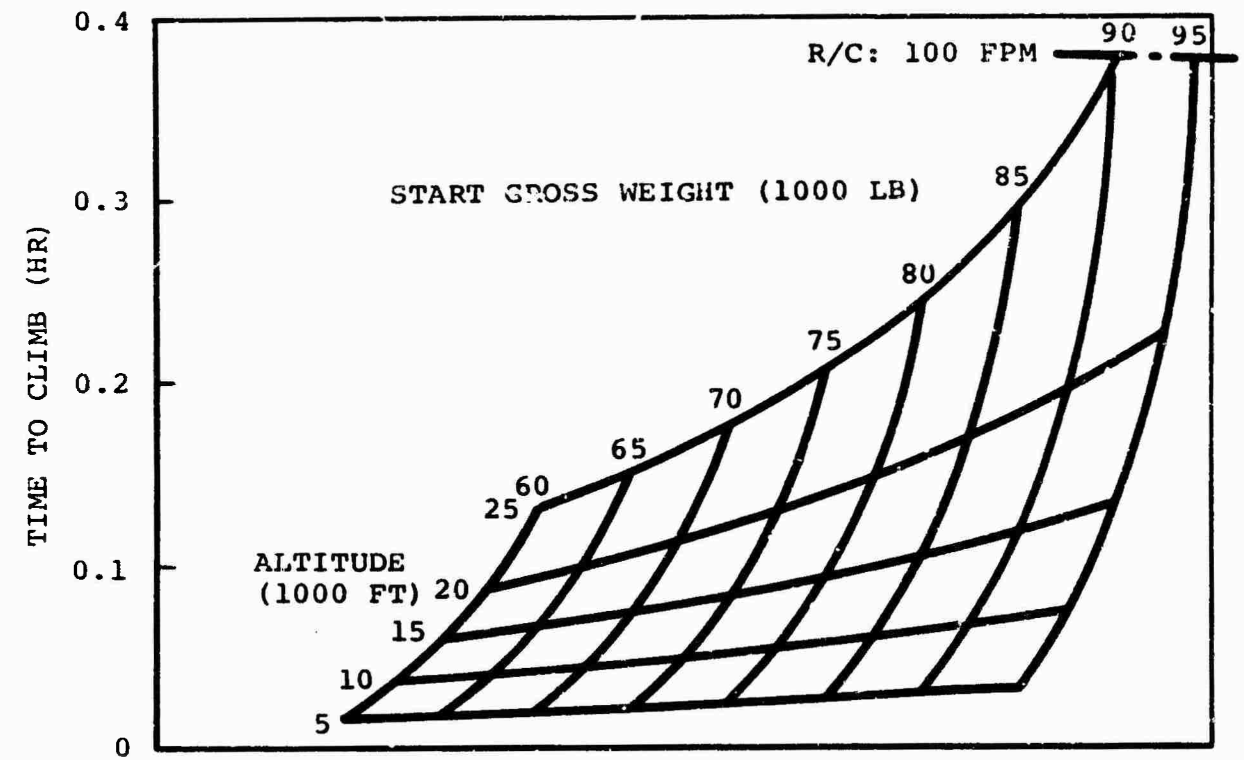


Figure 170. Design Point II Time to Climb From Sea Level at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

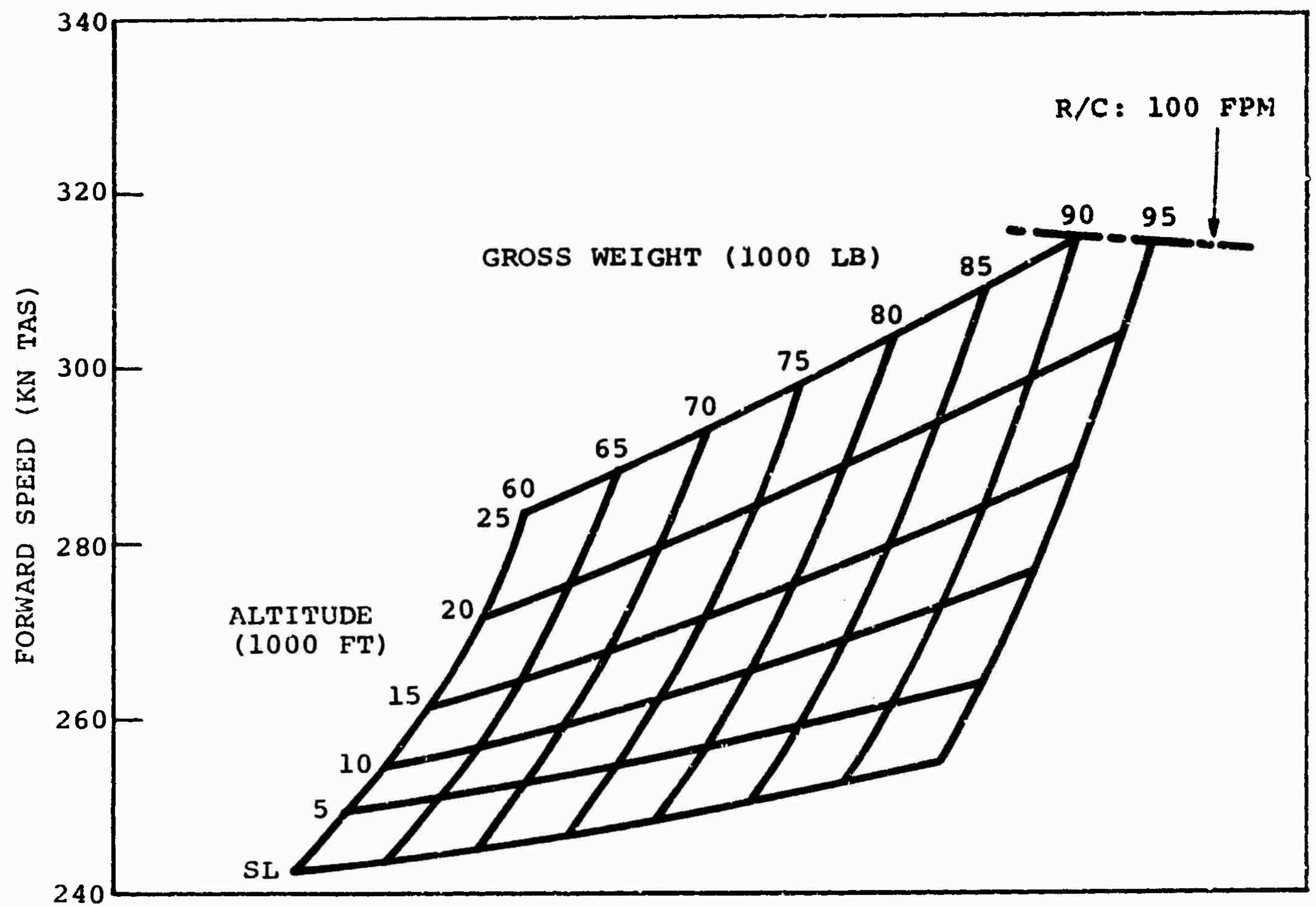


Figure 171. Design Point II Forward Speed at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

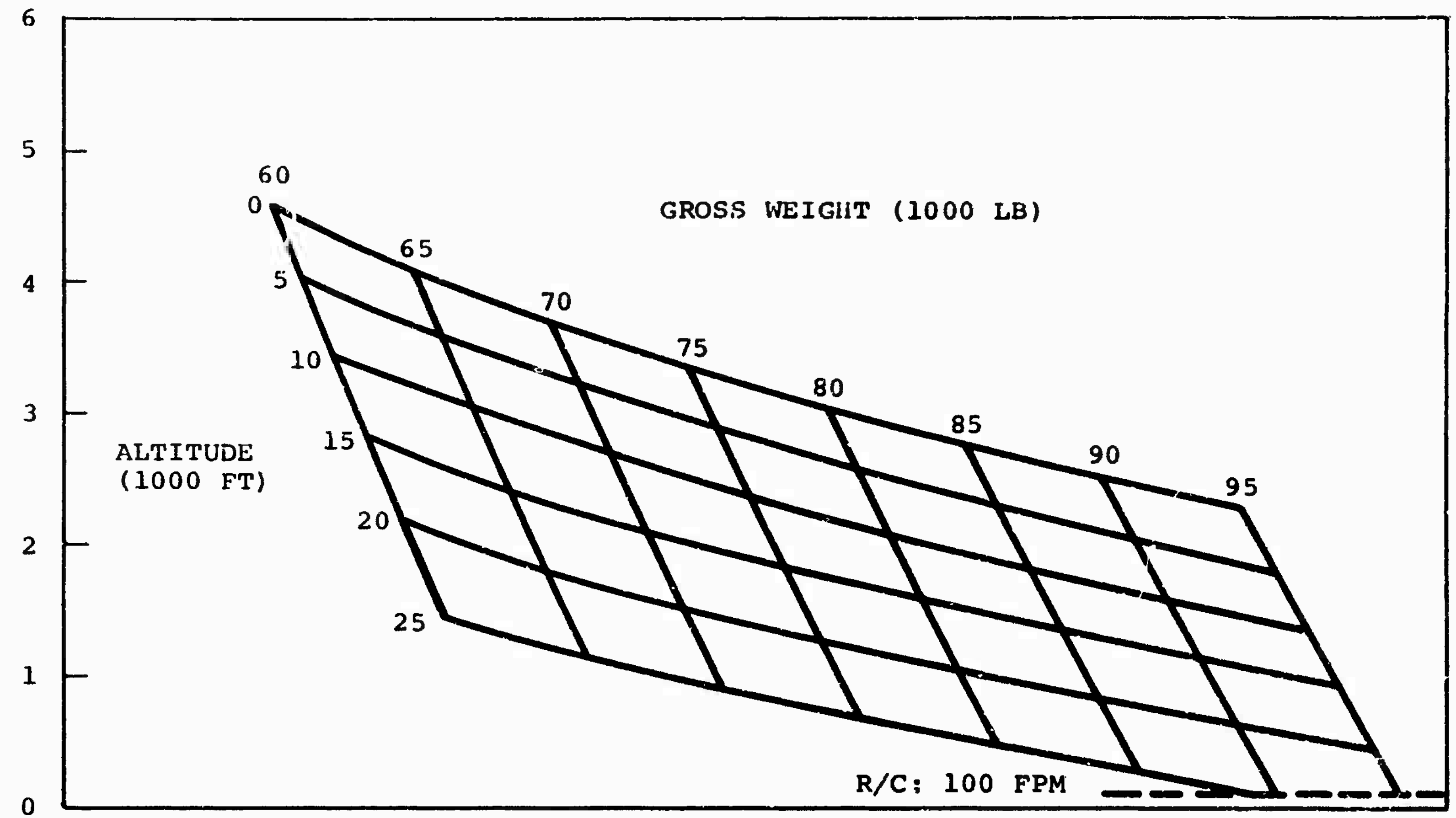


Figure 172. Design Point II Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

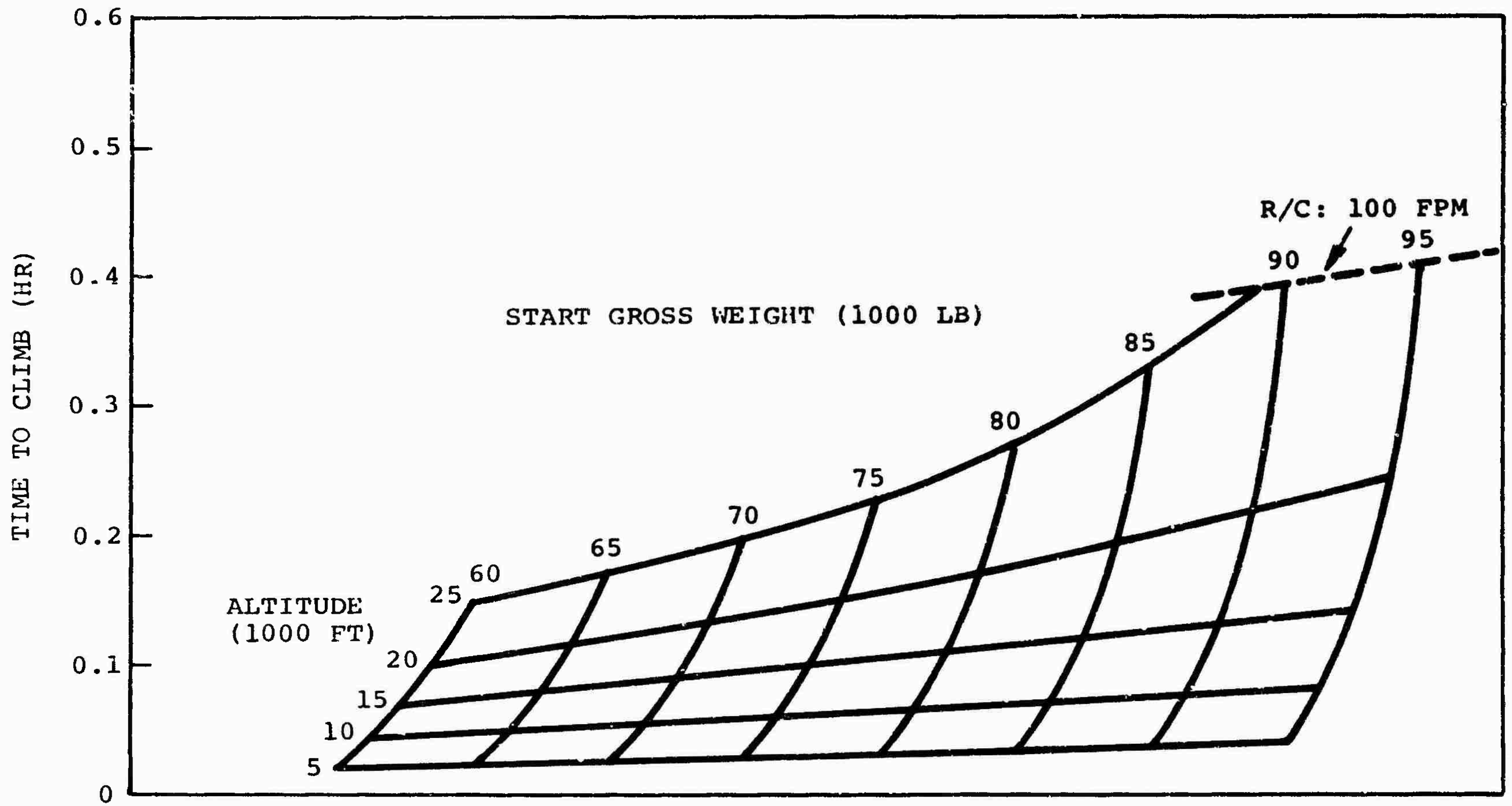


Figure 173. Design Point II Time to Climb From Sea Level at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

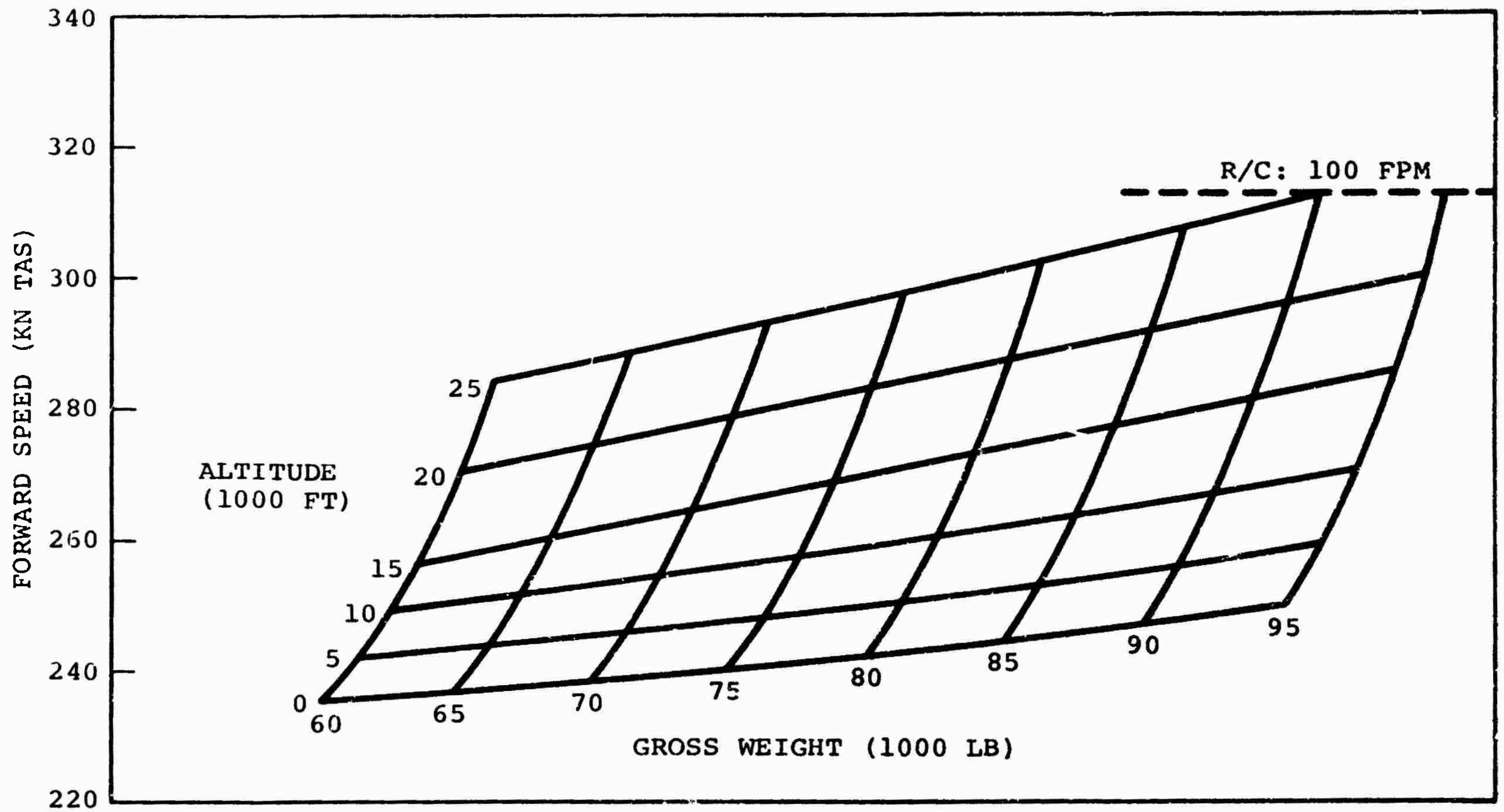


Figure 174. Design Point II Forward Speed at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

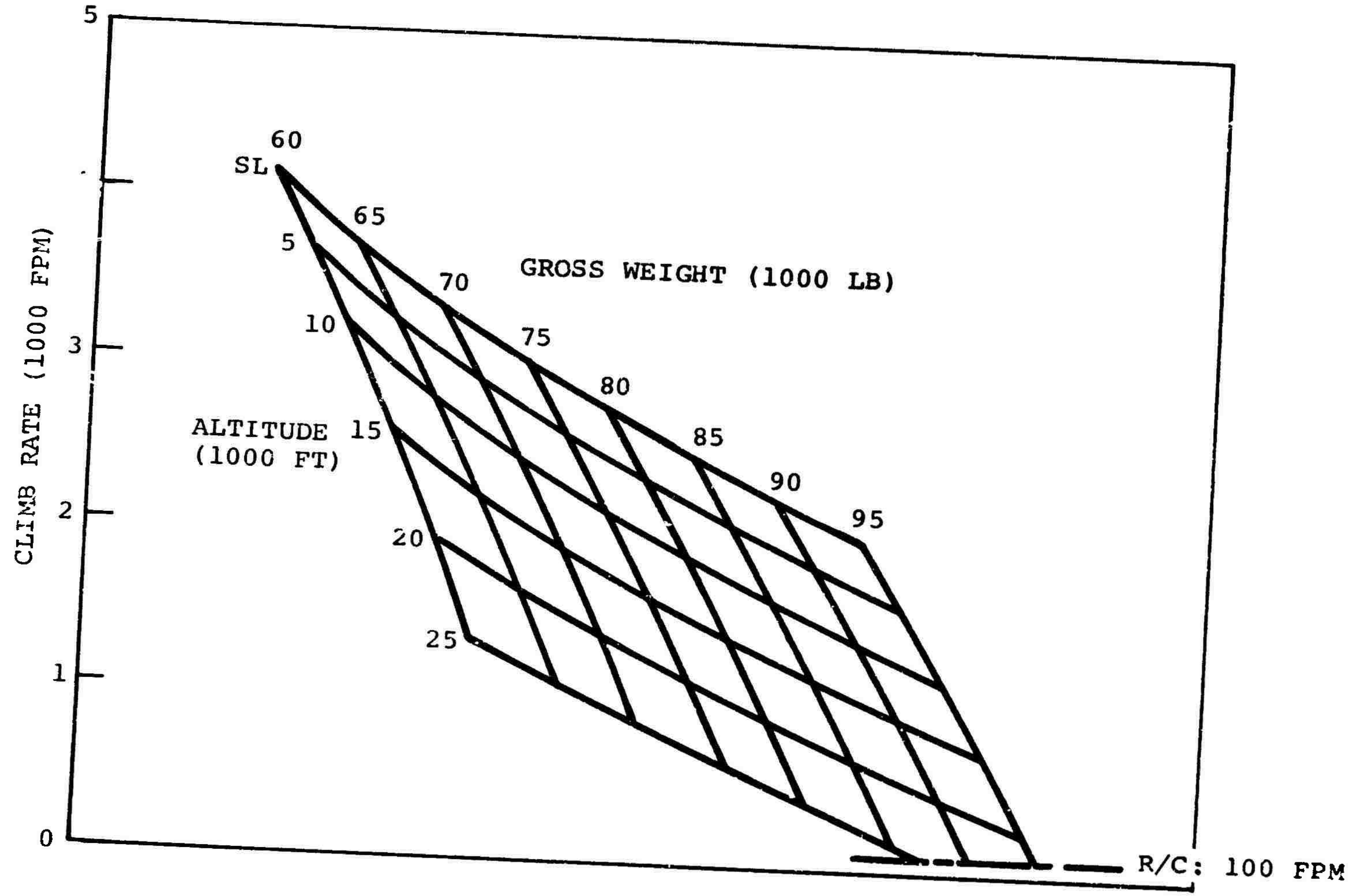


Figure 175. Design Point II Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

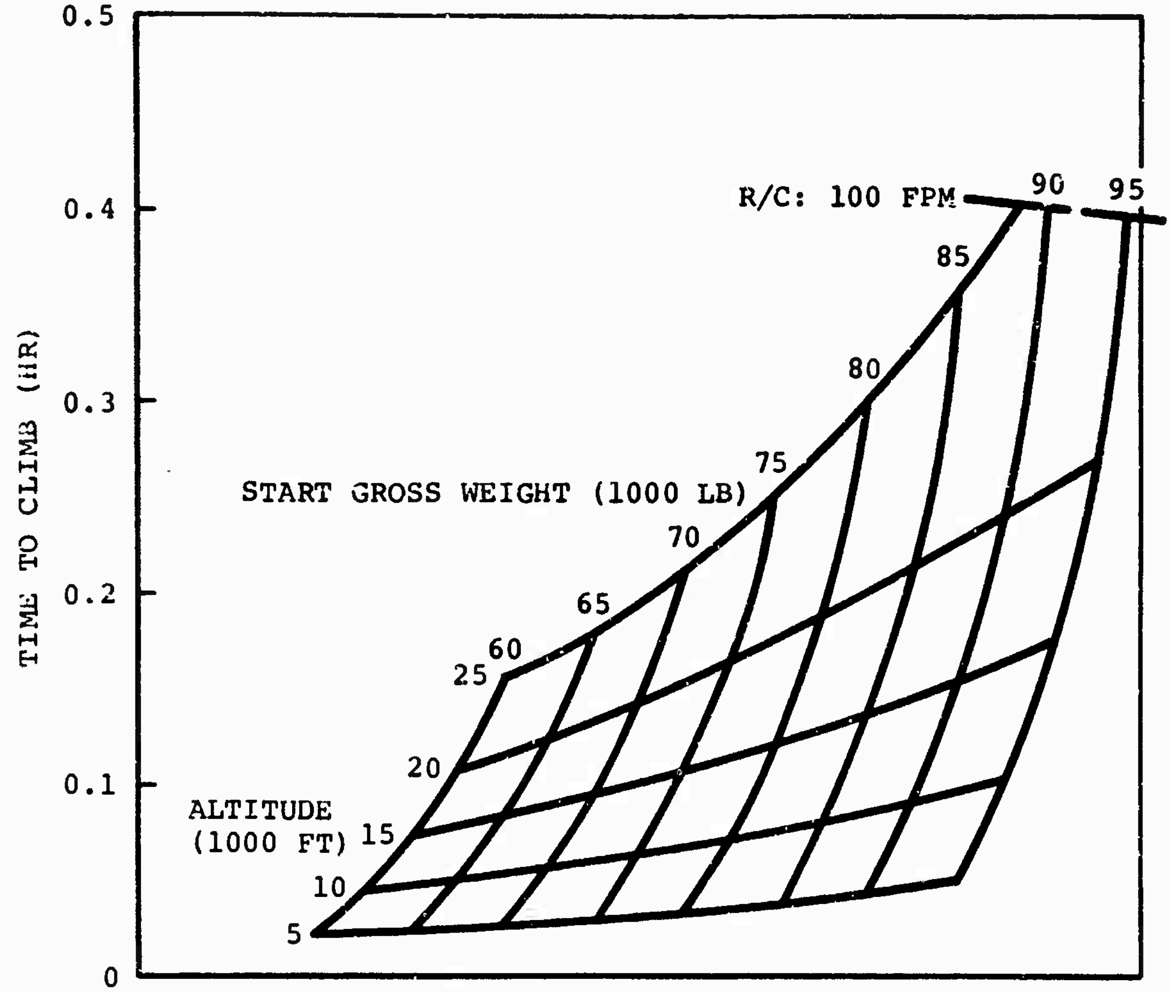


Figure 176. Design Point II Time to Climb From Sea Level at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

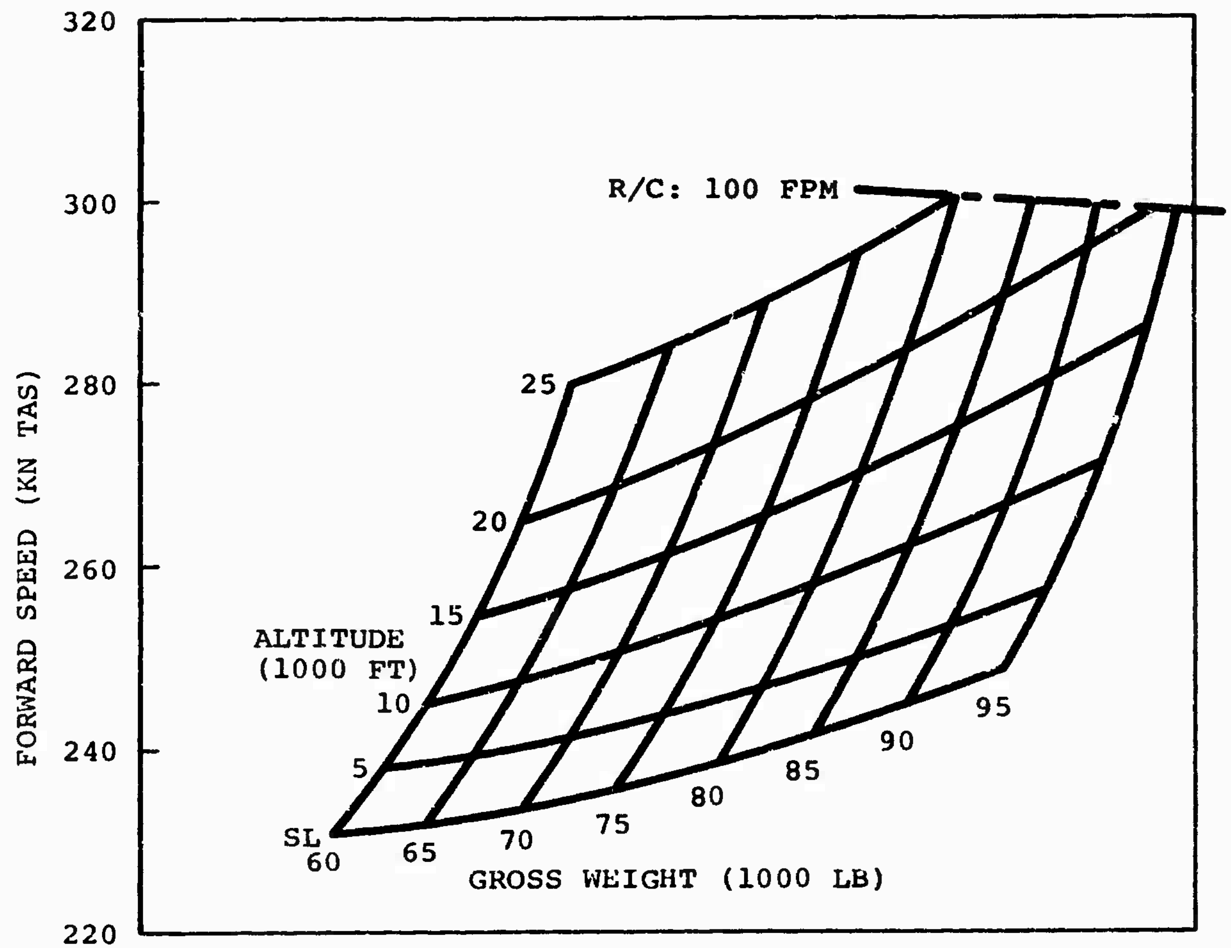


Figure 177. Design Point II Forward Speed at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

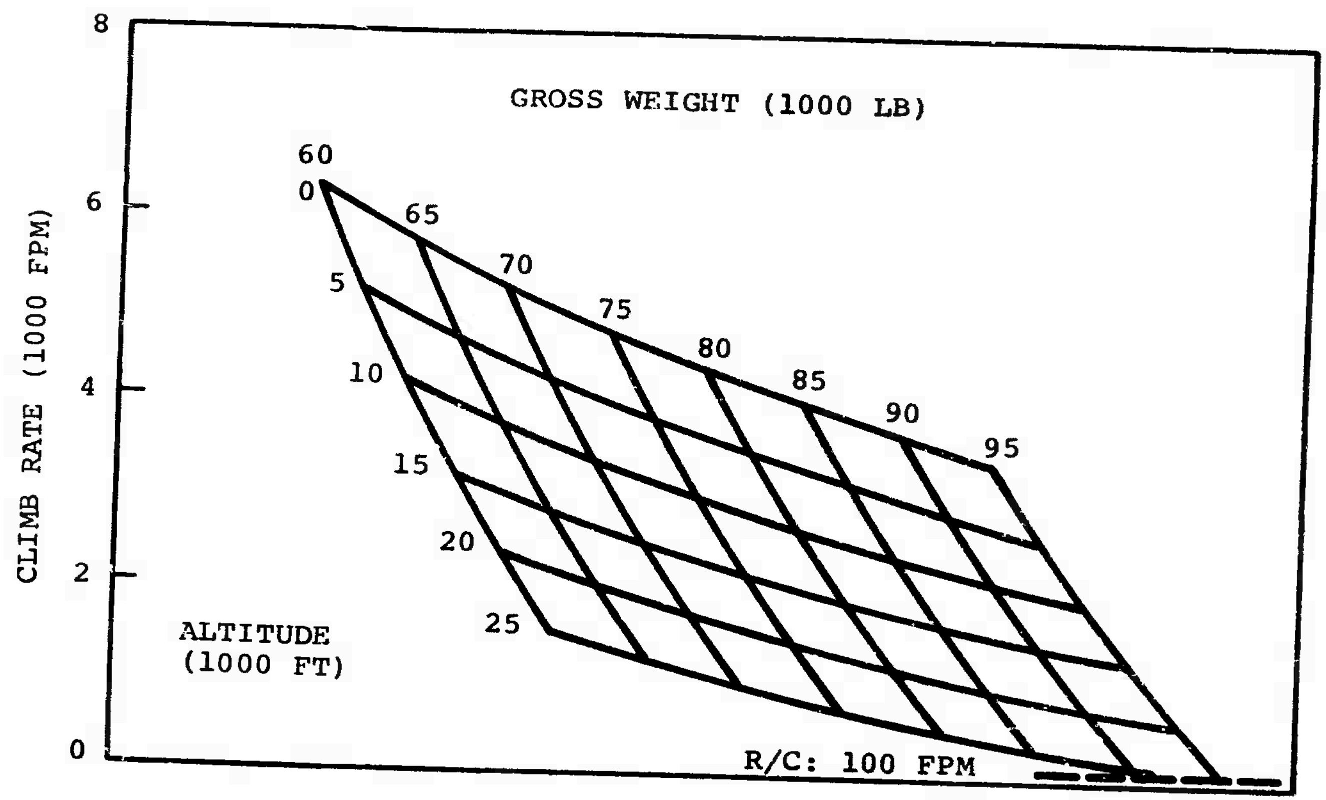


Figure 178. Design Point II Maximum Rate of Climb With Capsule for Standard Day With All Engines Operating at Maximum Power.

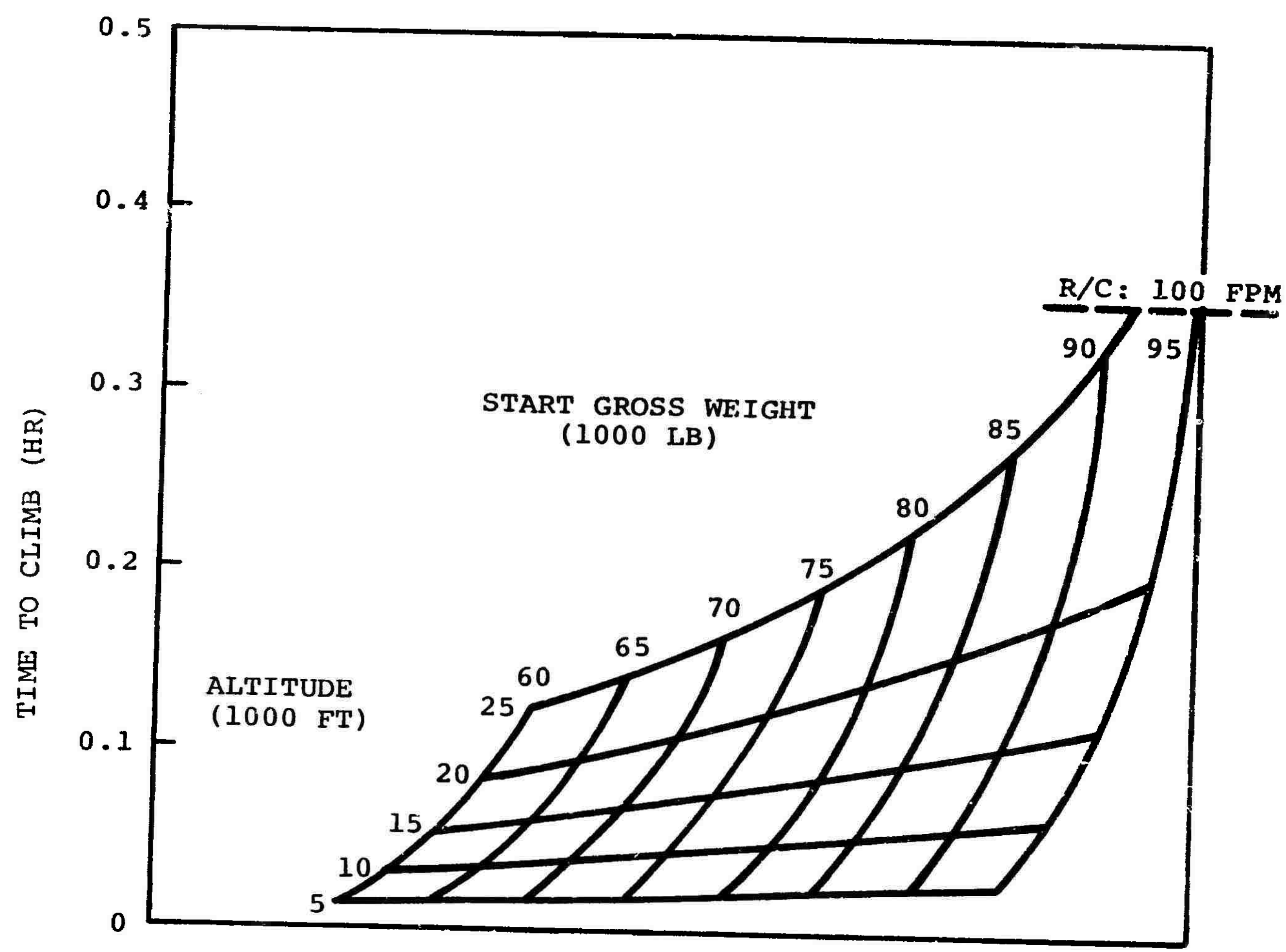


Figure 179. Design Point II Time to Climb From Sea Level (With Capsule) at Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

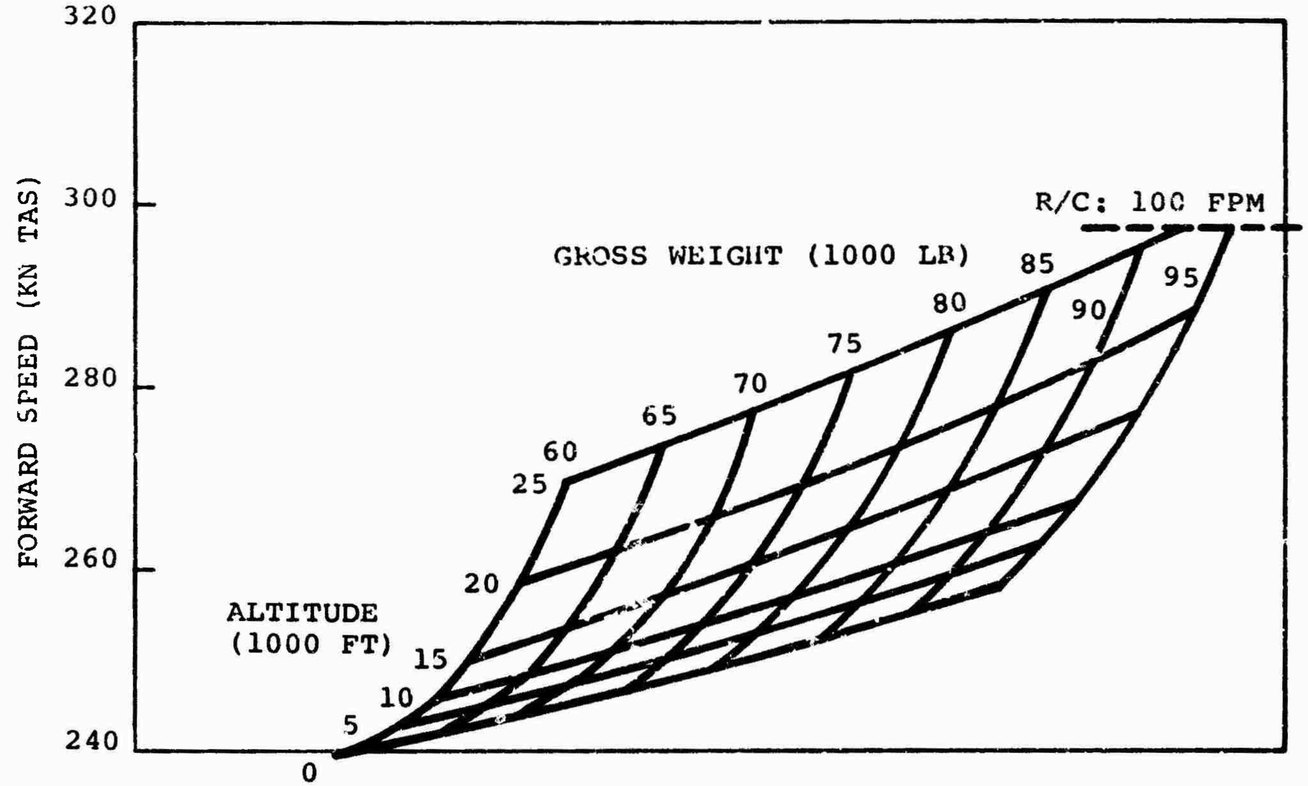


Figure 180. Design Point II Forward Speed (With Capsule) at Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

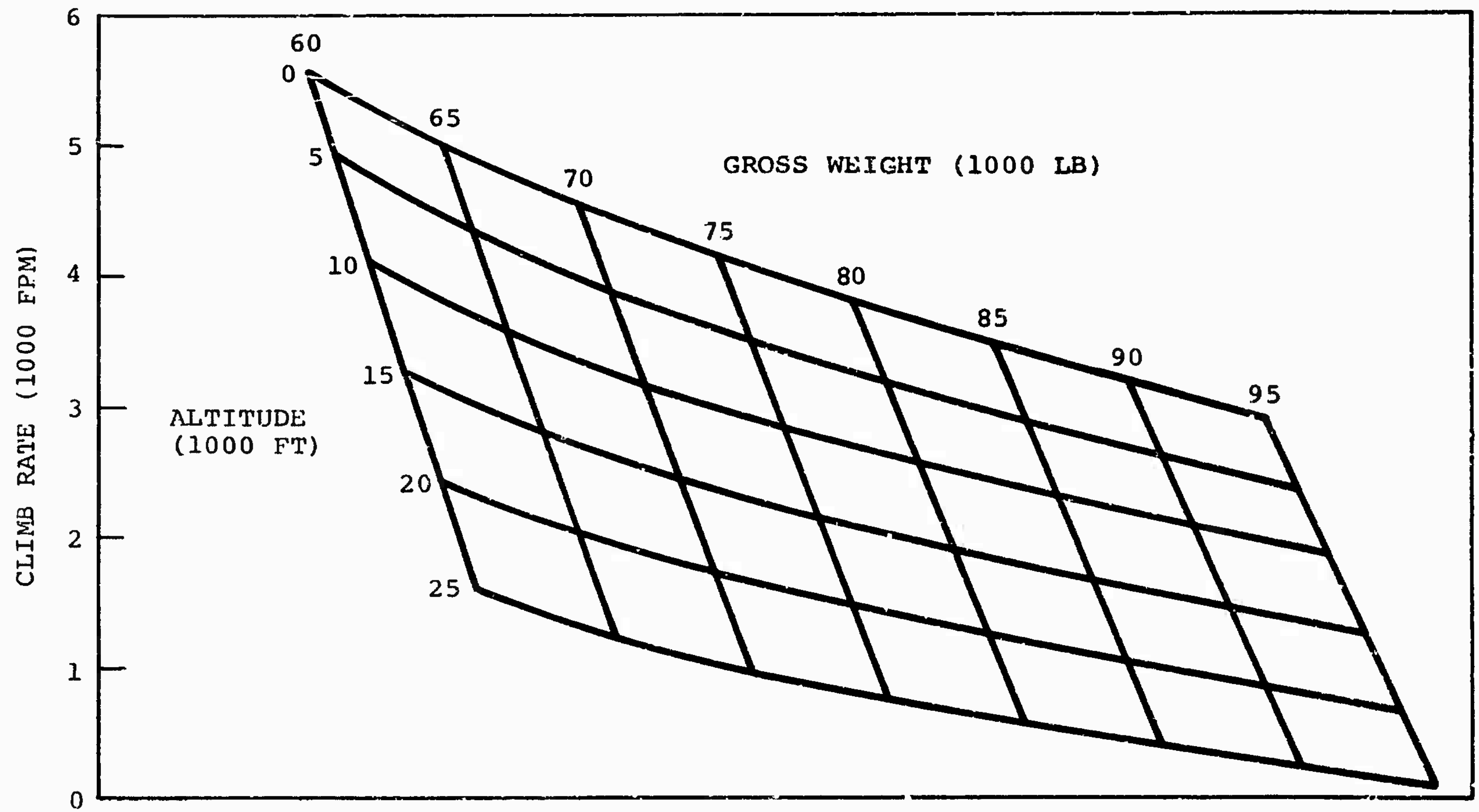


Figure 181. Design Point II Maximum Rate of Climb With Capsule for Standard Day With All Engines Operating at Military Power.

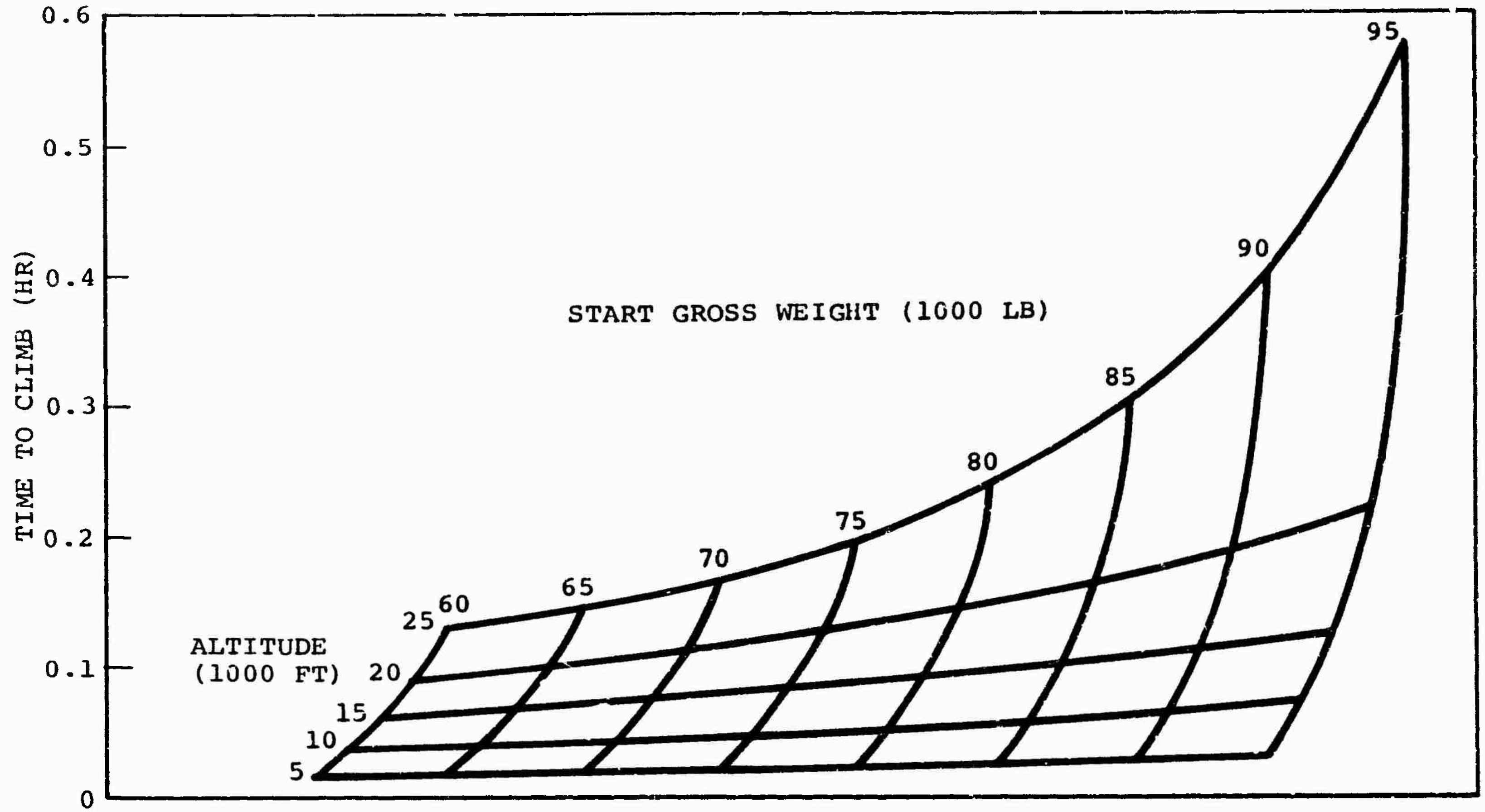


Figure 182. Design Point II Time to Climb From Sea Level With Capsule for Standard Day With All Engines Operating at Military Power.

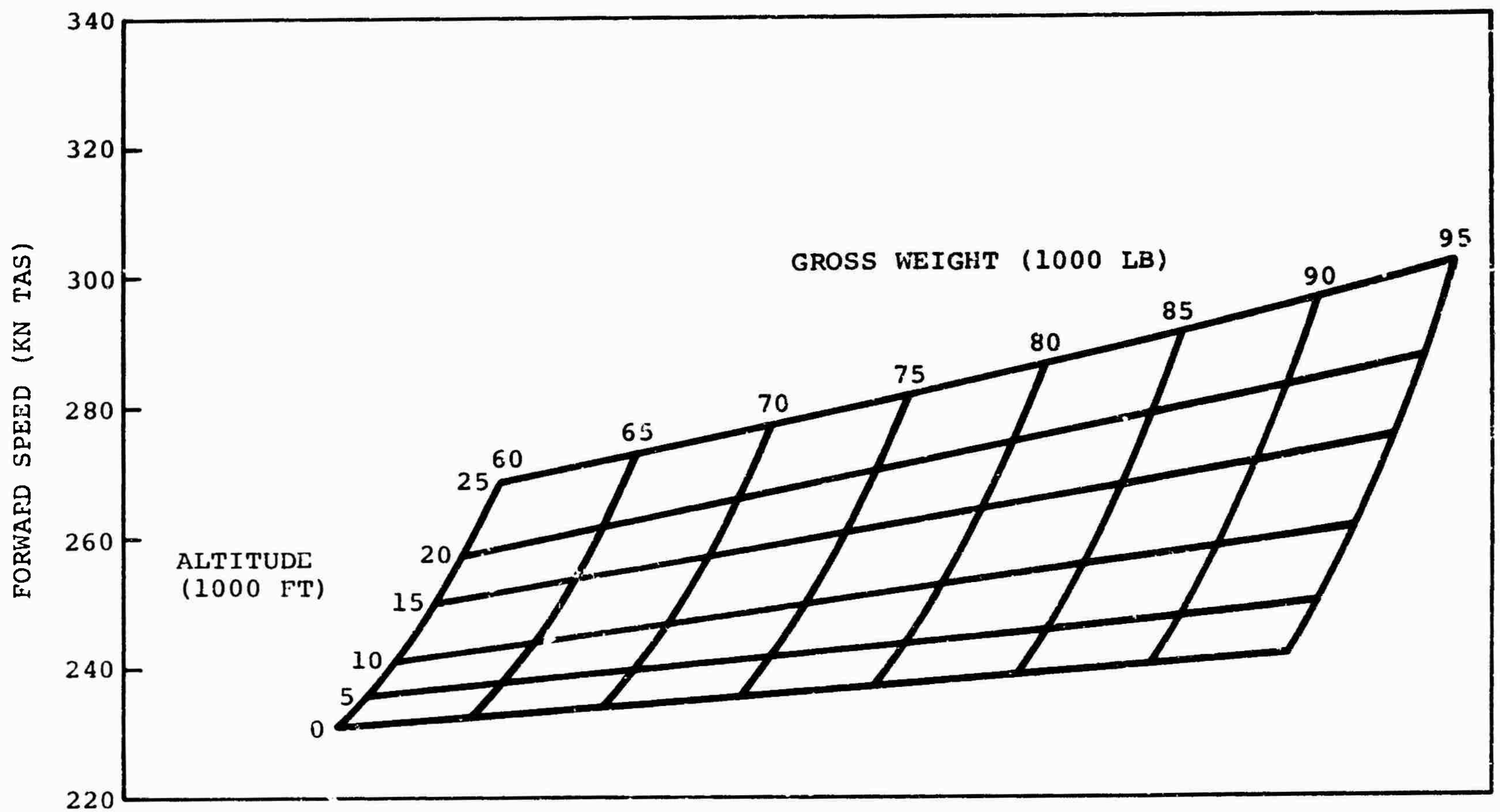


Figure 183. Design Point II Forward Speed (With Capsule) at Maximum Rate of Climb for Standard Day With All Engines Operating at Military Power.

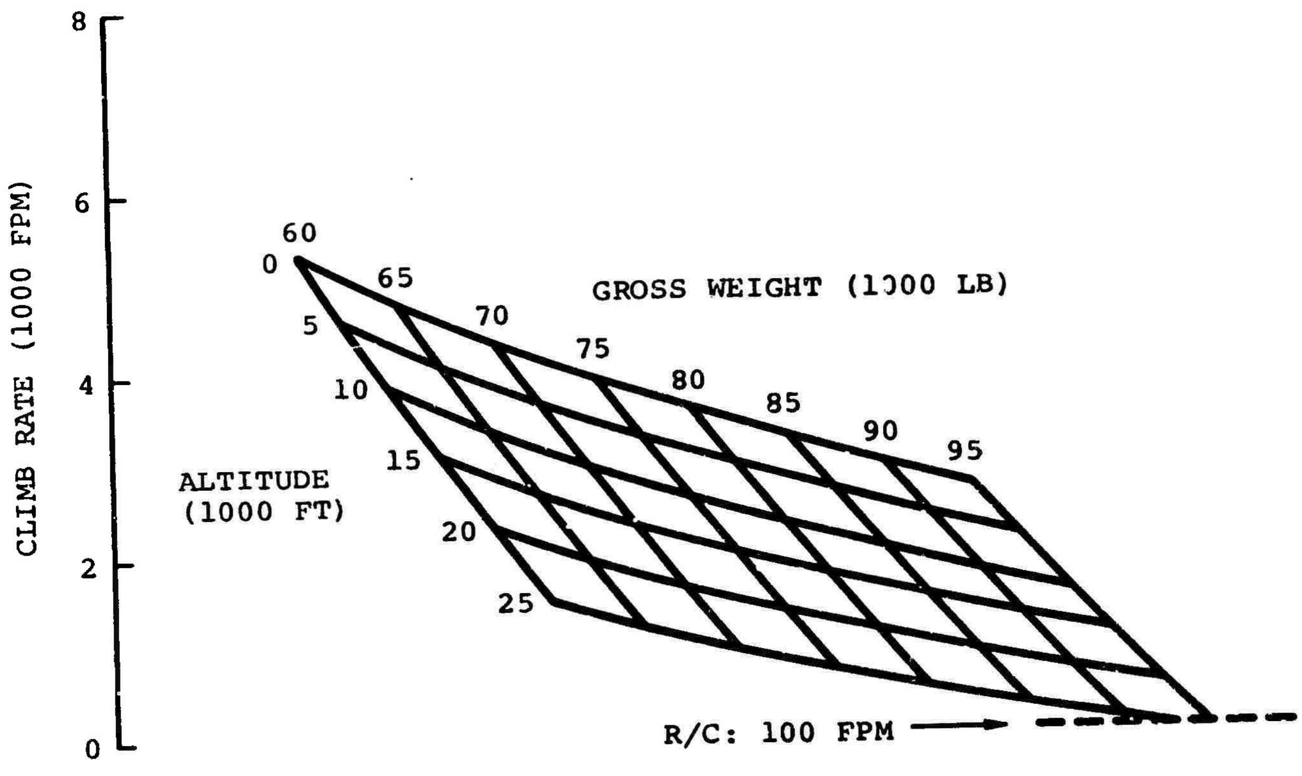


Figure 184. Design Point II Maximum Rate of Climb With Capsule for Standard Day With All Engines Operating at Normal Rated Power.

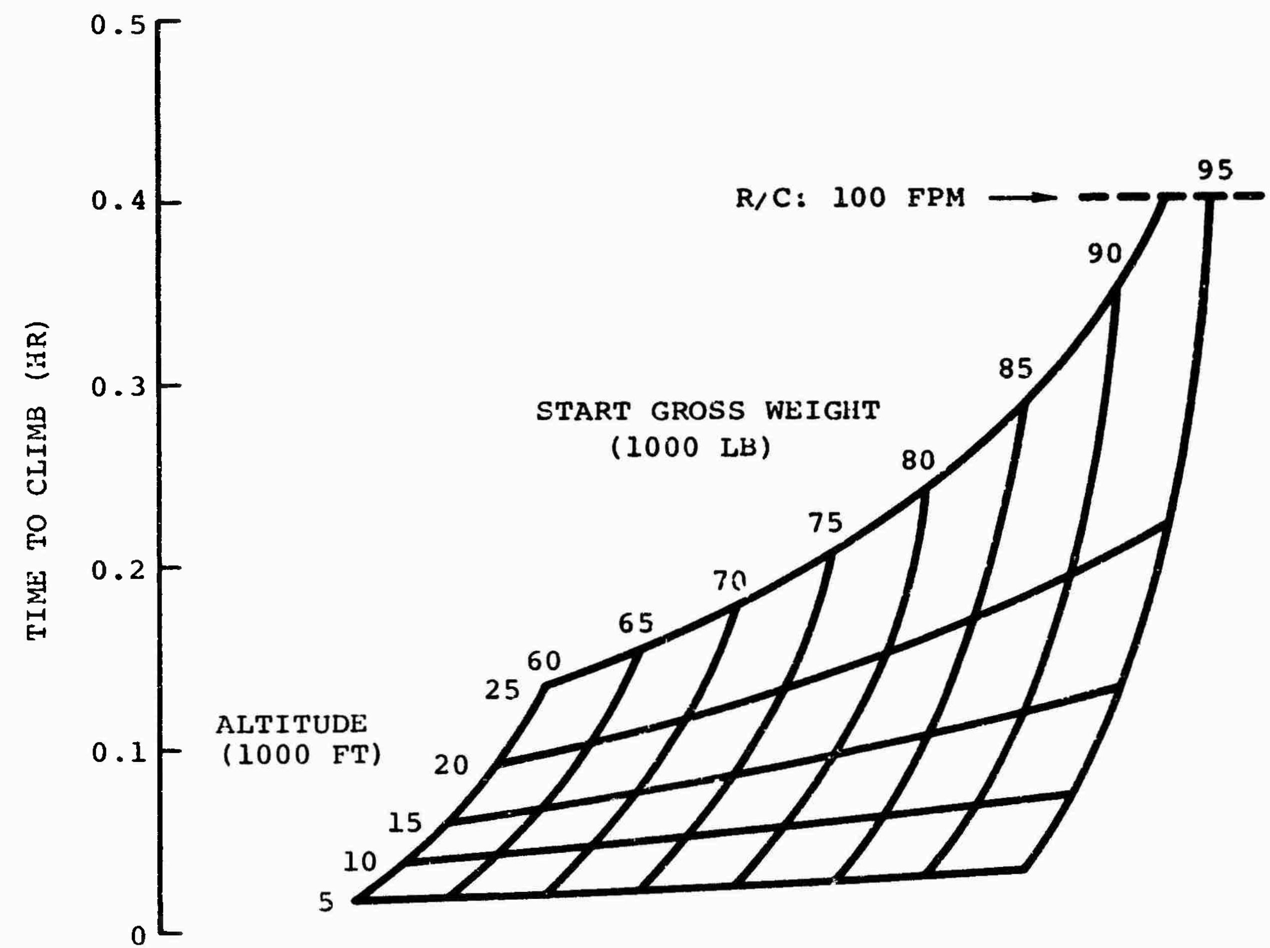


Figure 185. Design Point II Time to Climb From Sea Level With Capsule at Maximum Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.

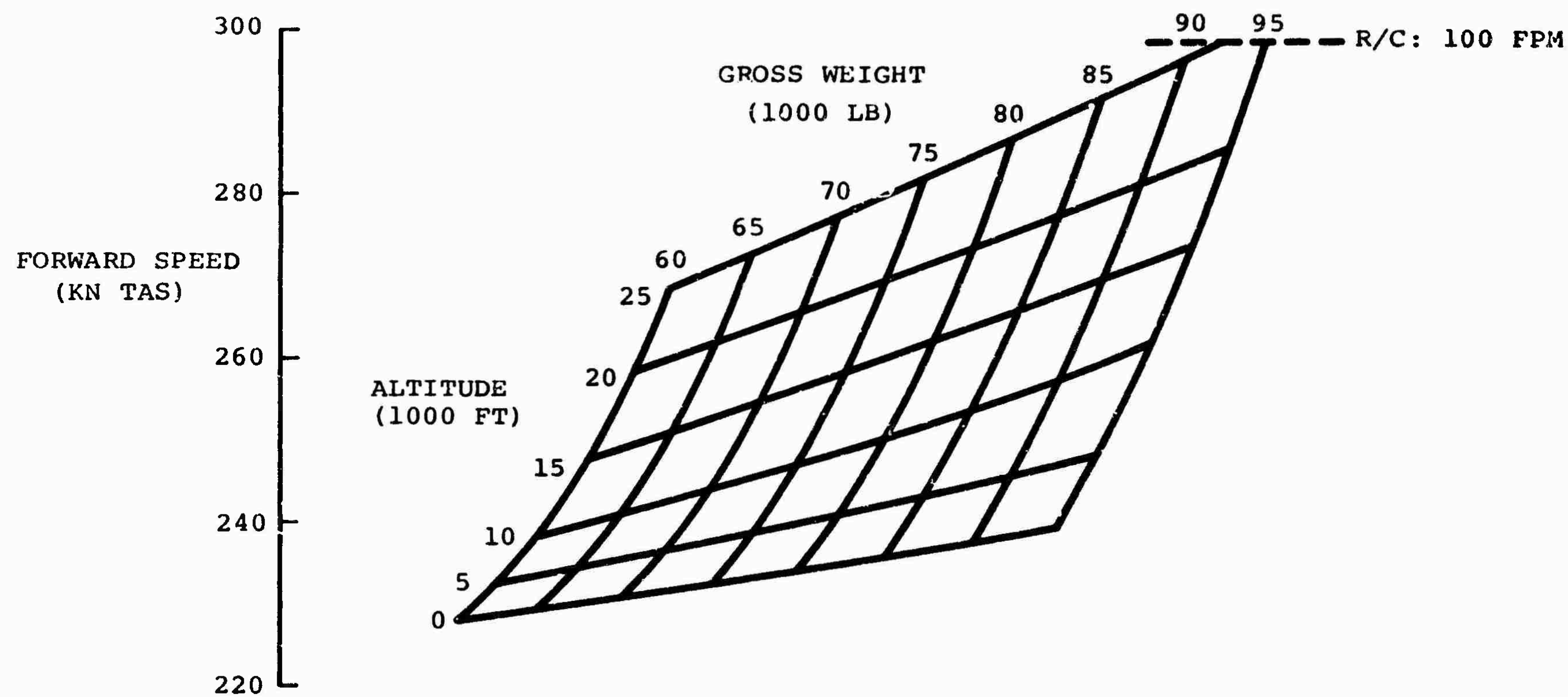


Figure 186. Design Point II Forward Speed (With Capsule) at Maxi.num Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.

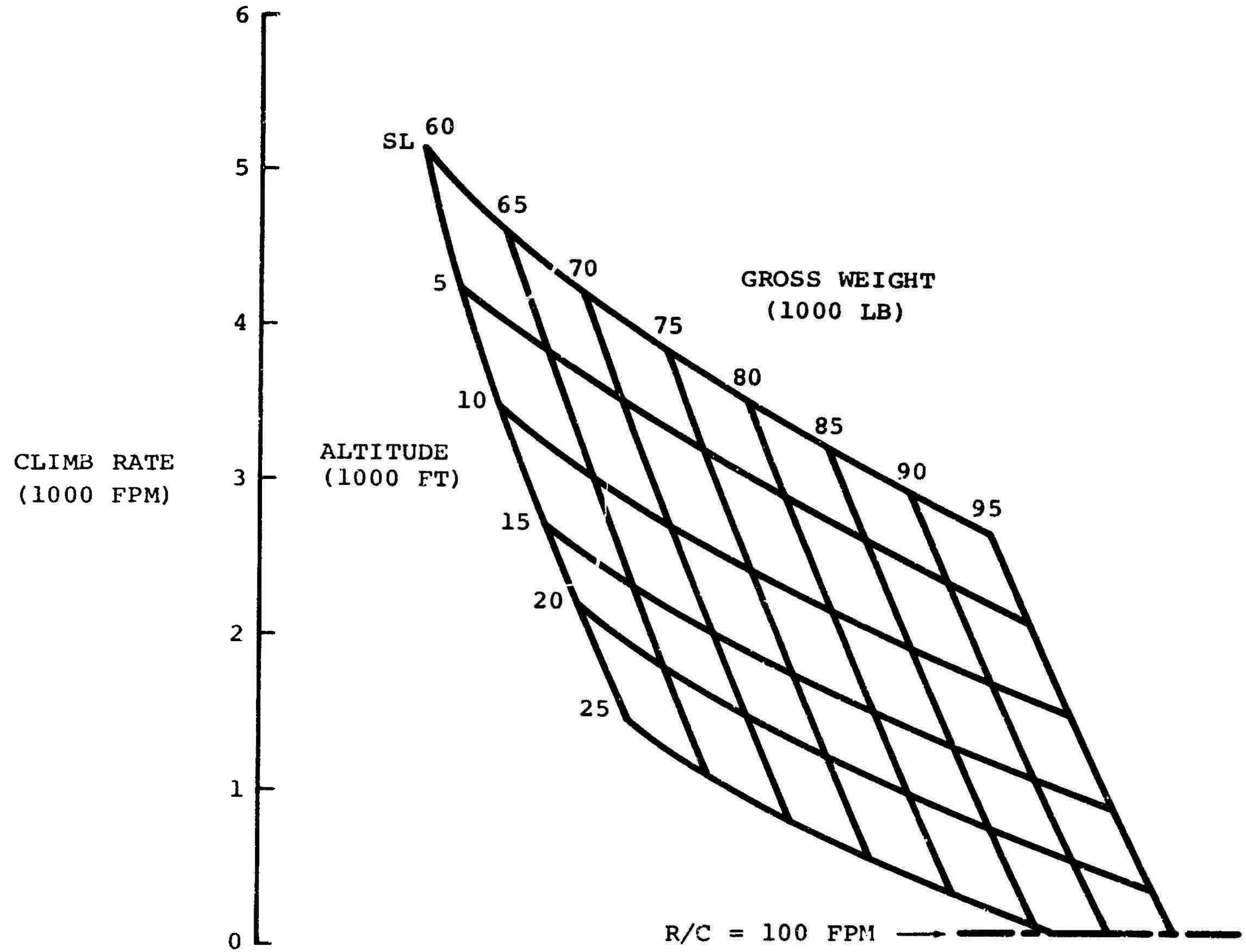


Figure 187. Design Point II Maximum Rate of Climb (With Capsule) for Air Force Hot Day With All Engines Operating at Maximum Power.

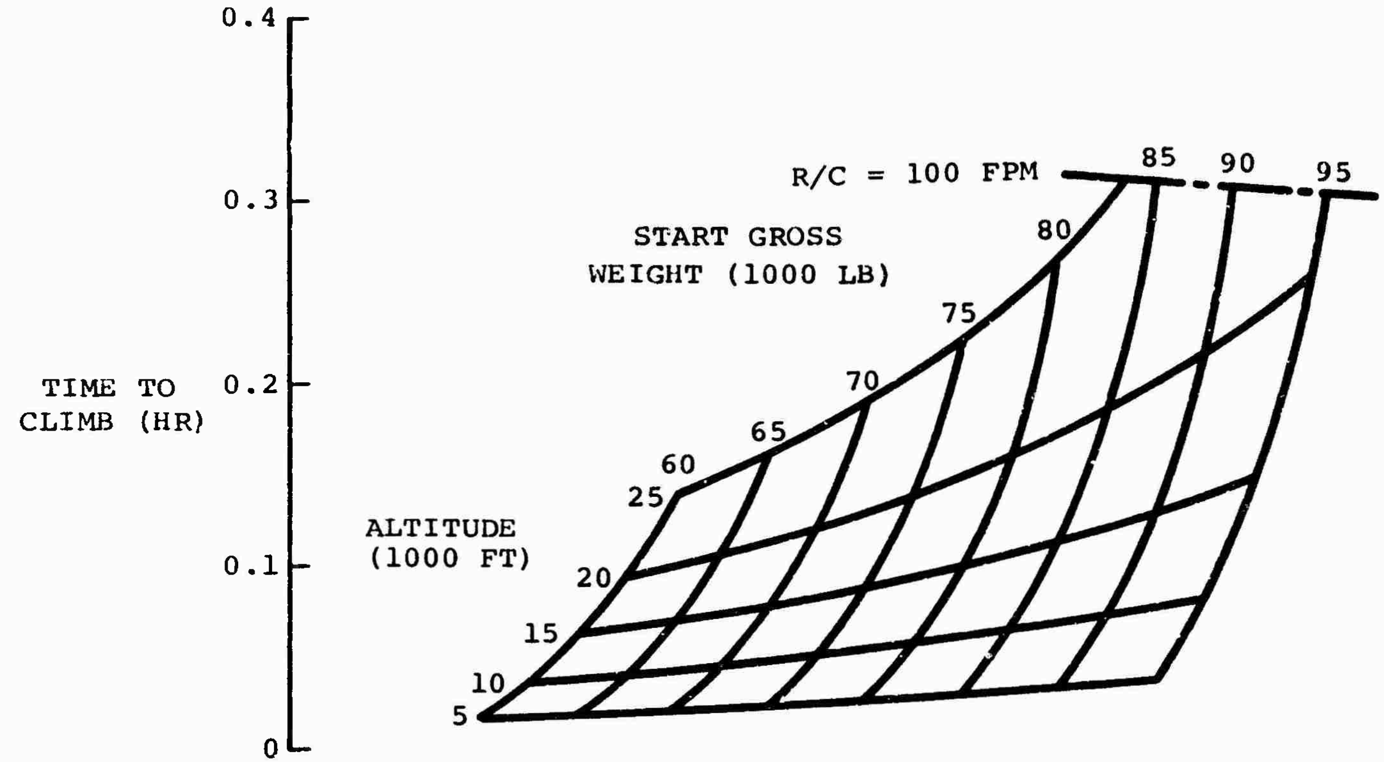


Figure 188. Design Point II Time to Climb From Sea Level (With Capsule) at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

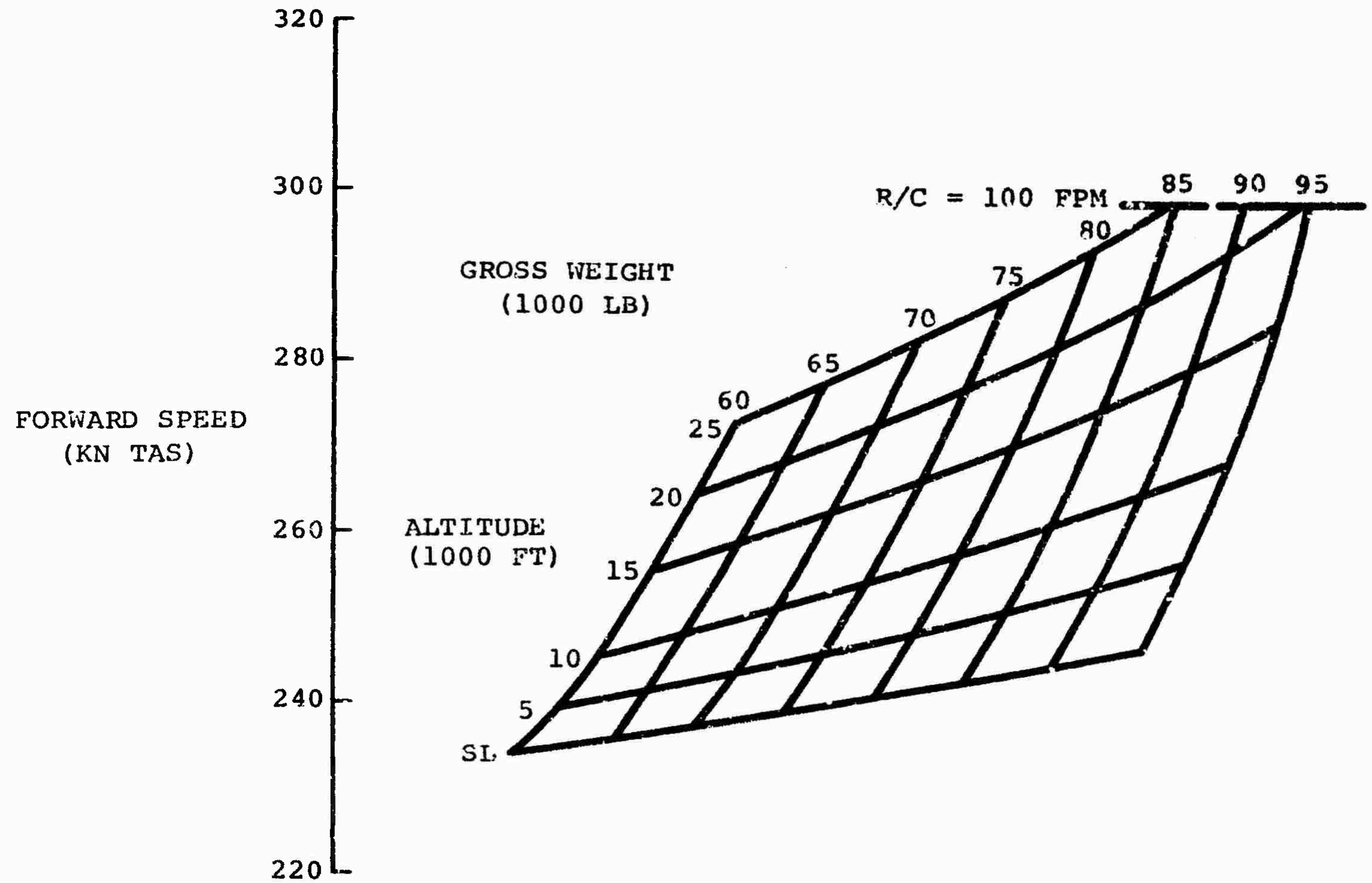


Figure 189. Design Point II Forward Speed (With Capsule) at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

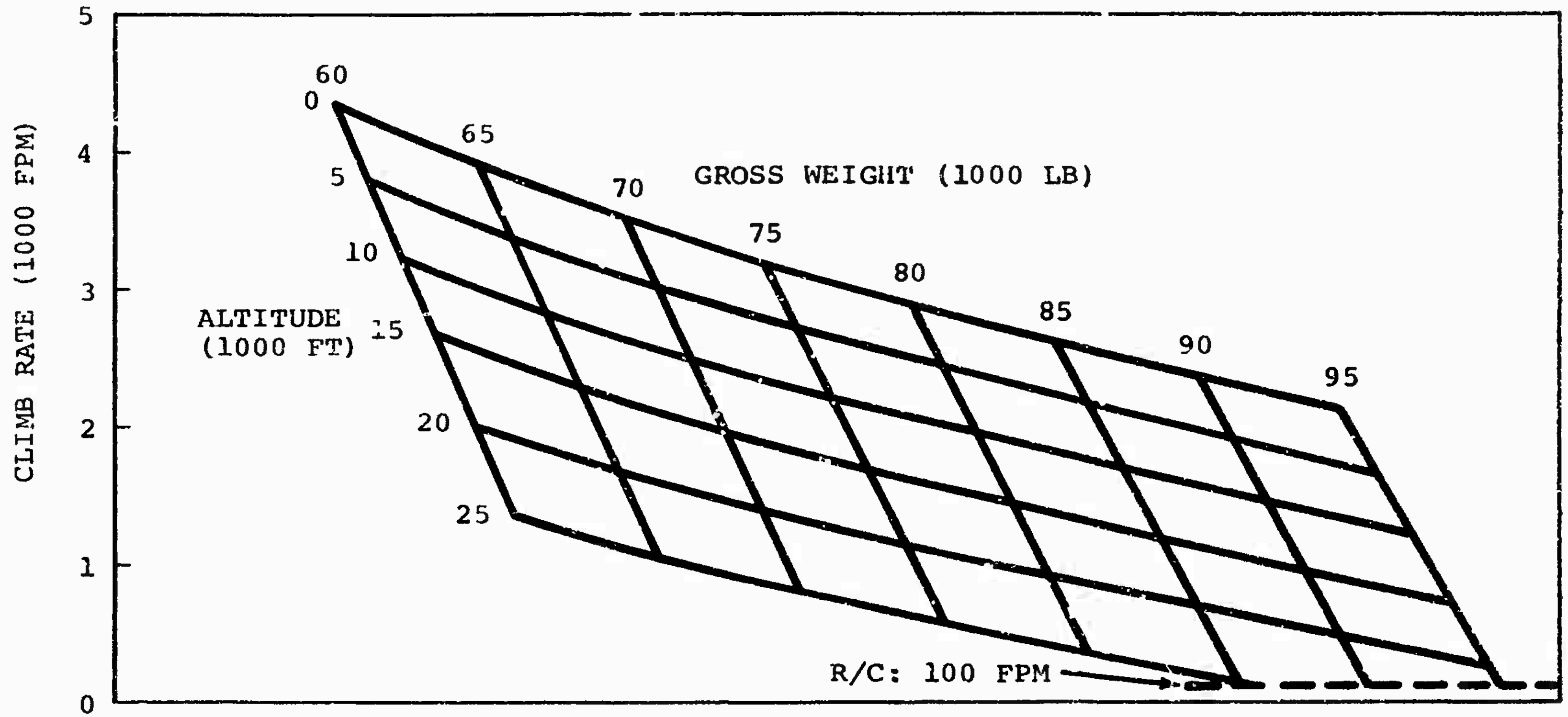


Figure 190. Design Point II Maximum Rate of Climb With Capsule for Air Force Hot Day With All Engines Operating at Military Power.

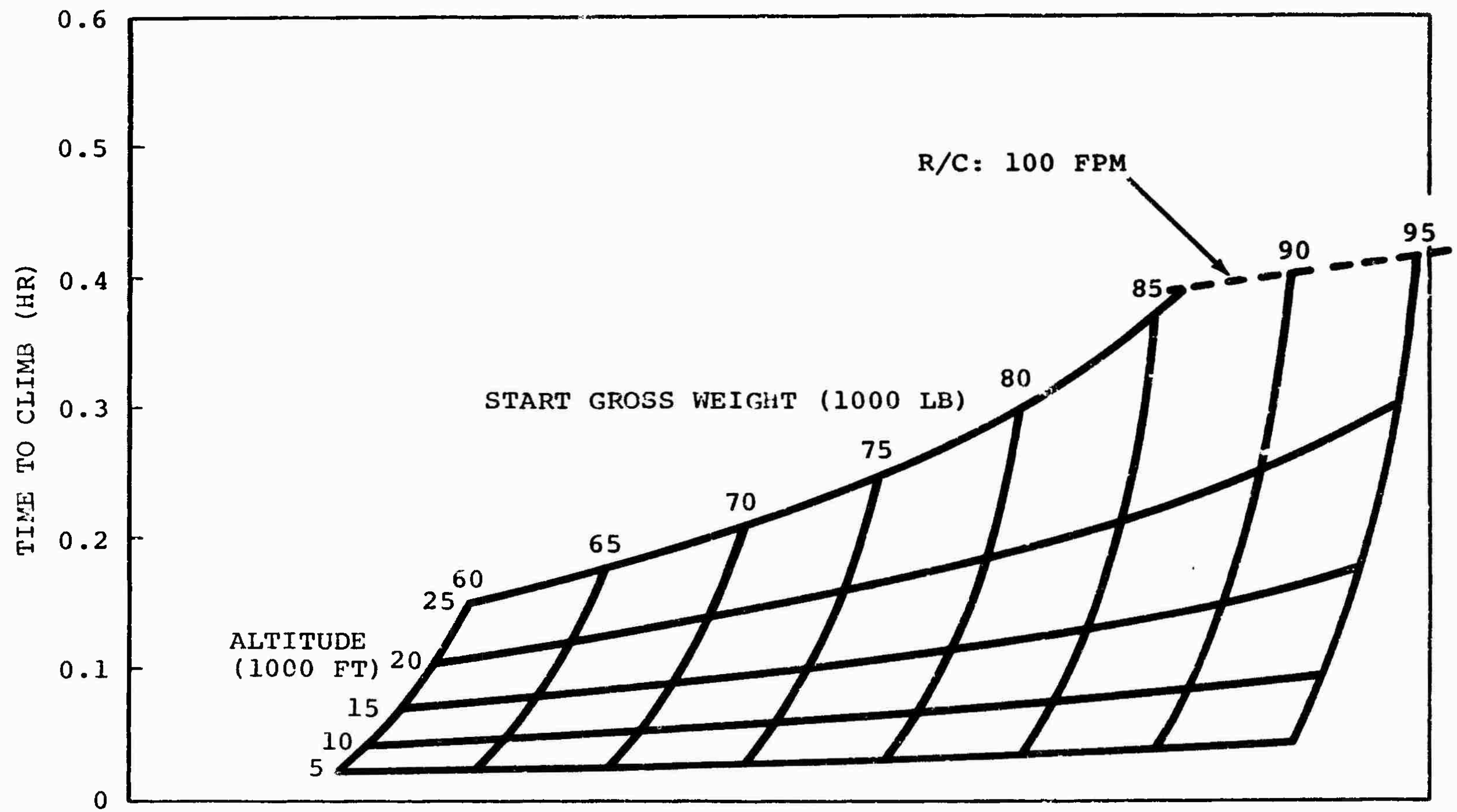


Figure 191. Design Point II Time to Climb From Sea Level With Capsule at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

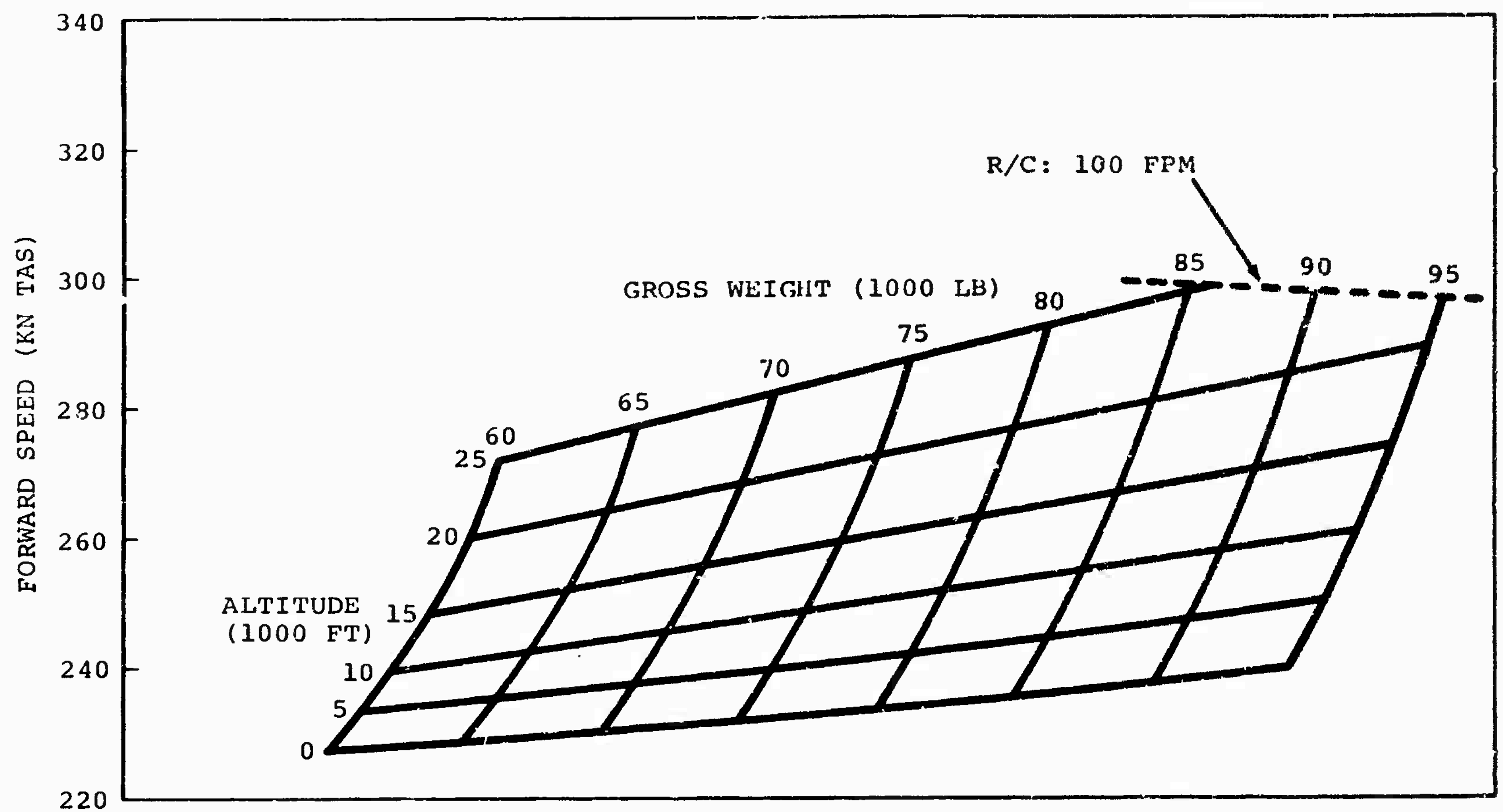


Figure 192. Design Point II Forward Speed (With Capsule) at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

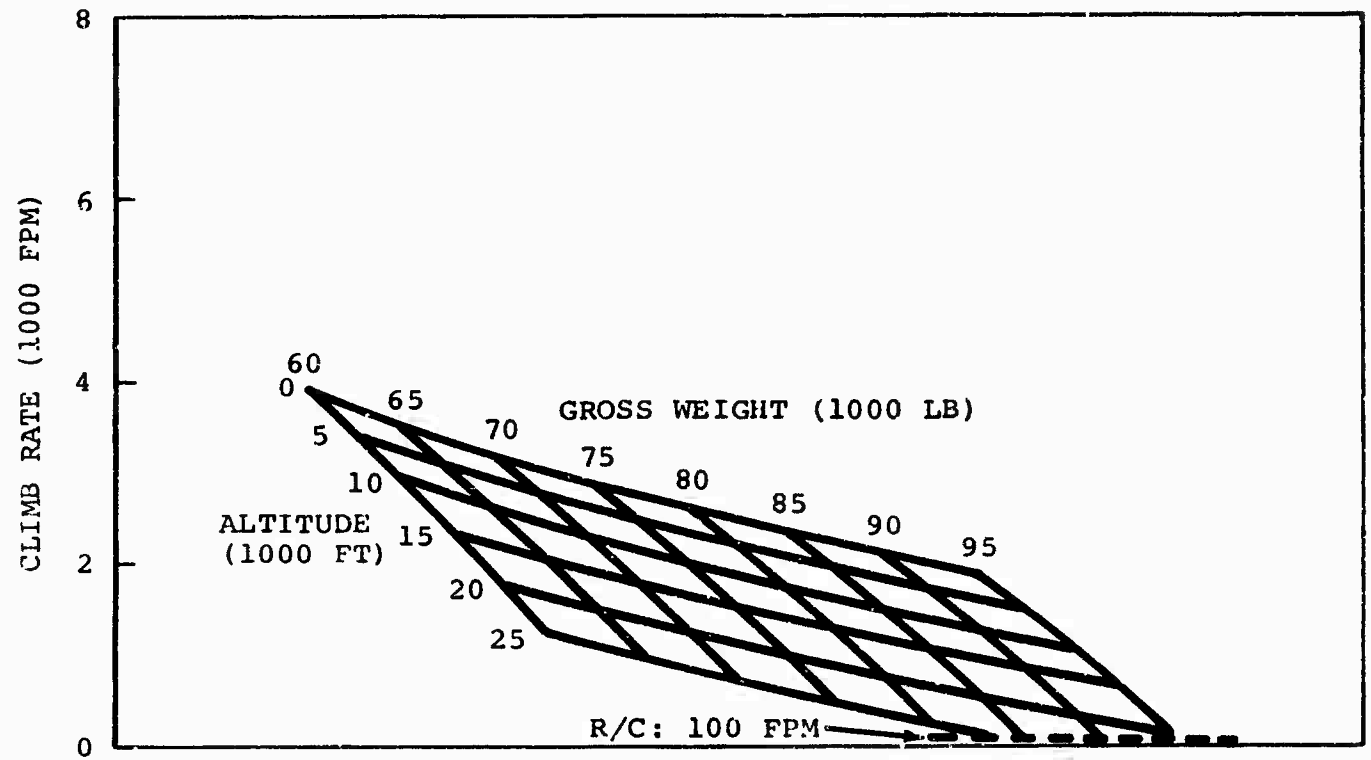


Figure 193. Design Point II Maximum Rate of Climb With Capsule for Air Force Hot Day With All Engines Operating at Normal Rated Power.

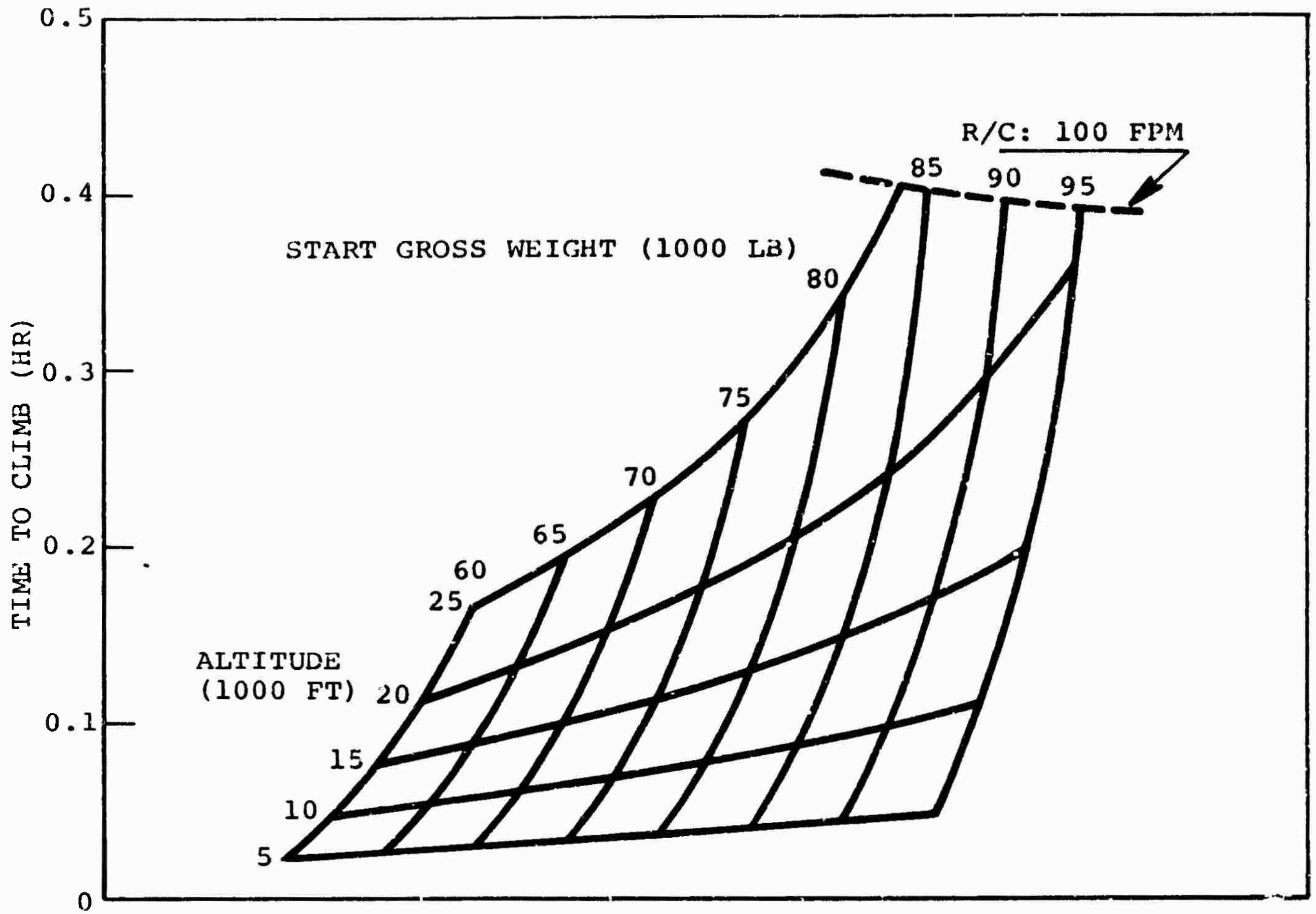


Figure 194. Design Point II Time to Climb From Sea Level With Capsule at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

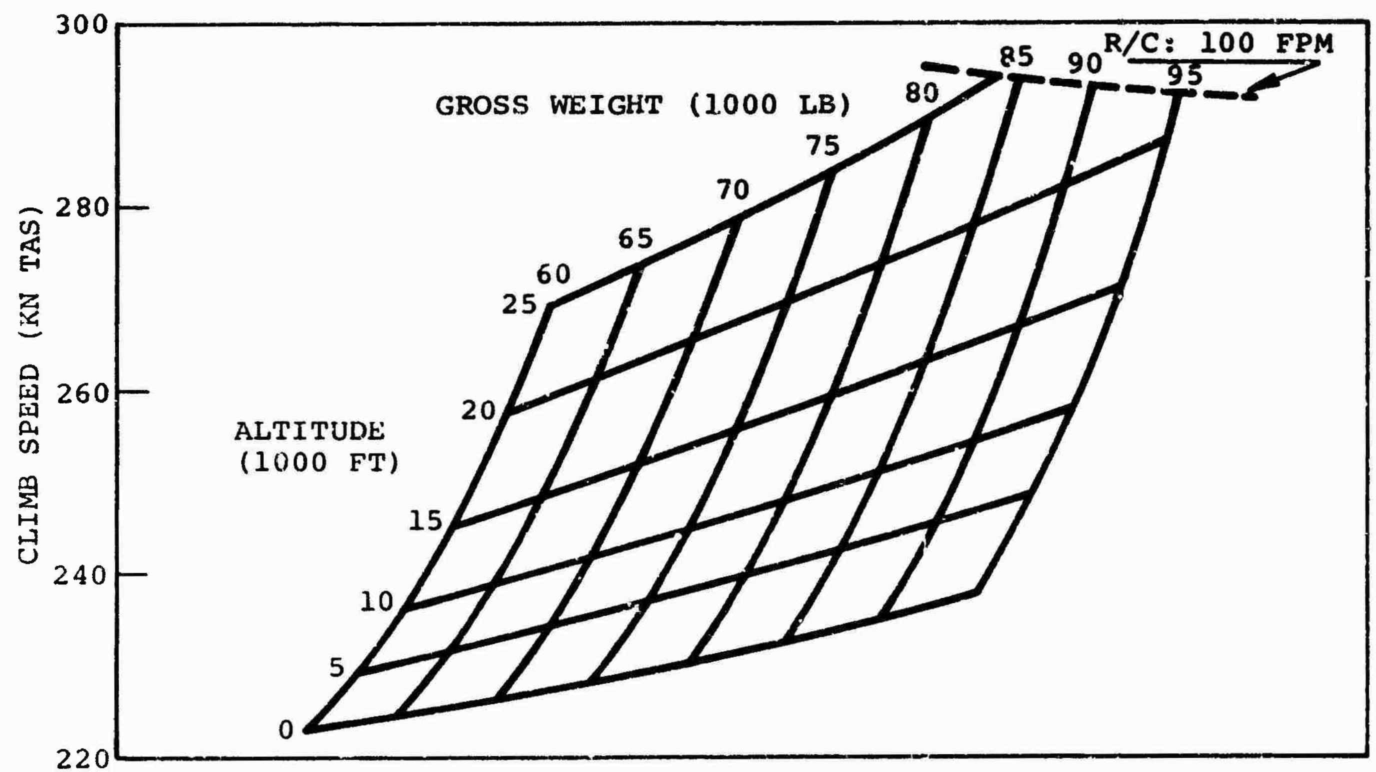


Figure 195. Design Point II Climb Speed With Capsule at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

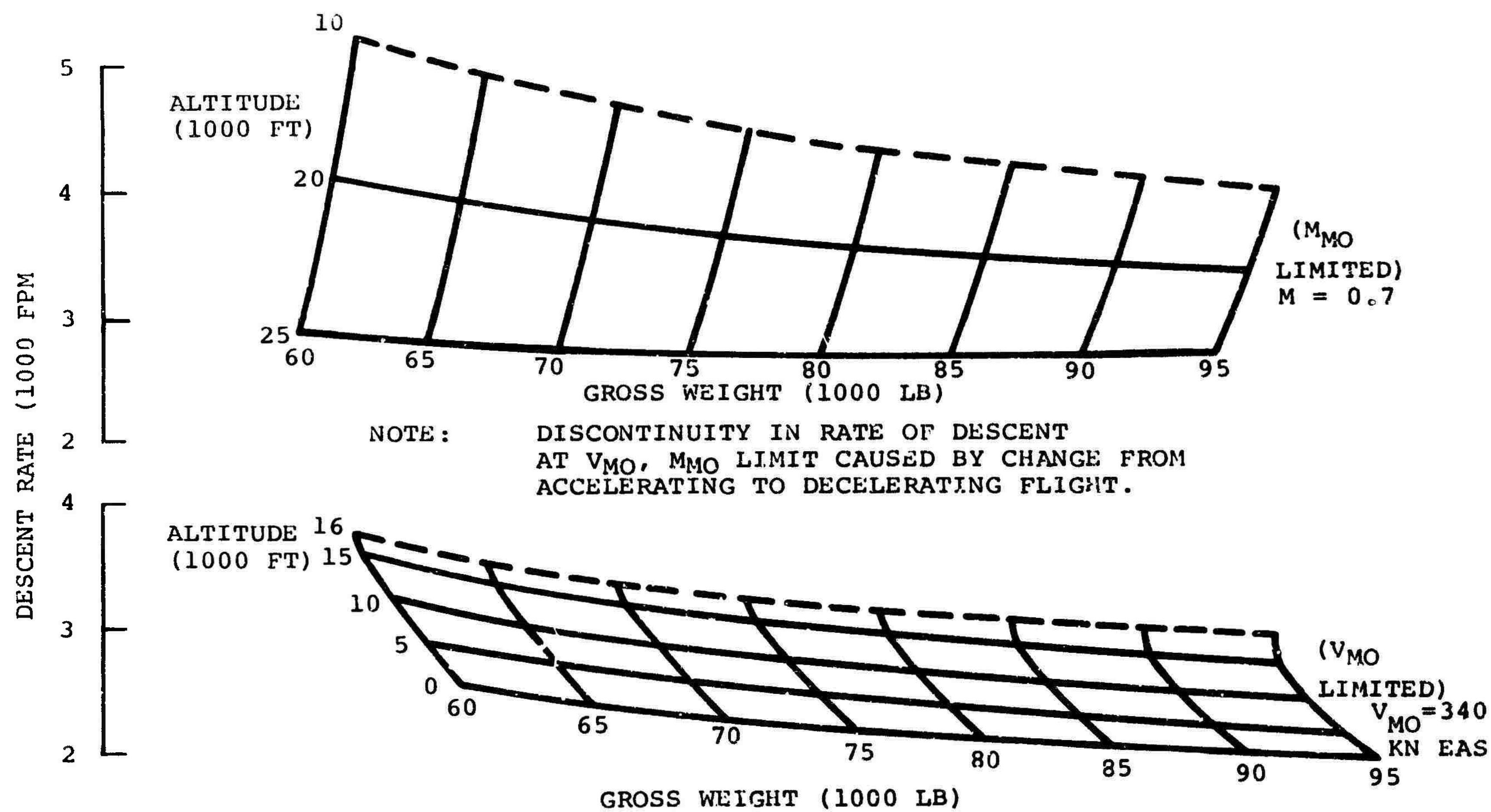


Figure 196. Design Point II Maximum Rate of Descent for Standard Day With All Engines Operating at Flight Idle Power.

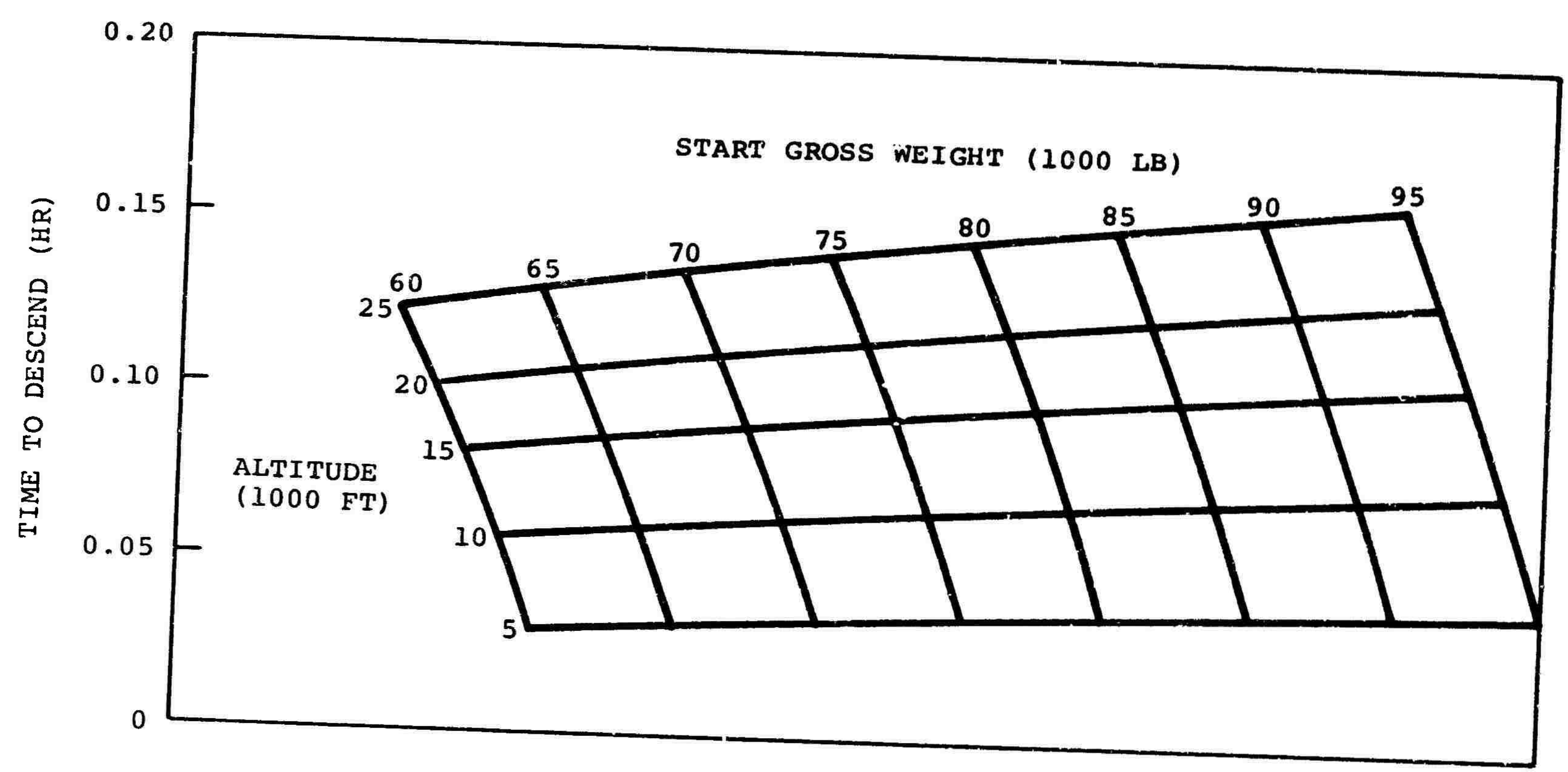


Figure 197. Design Point II Time to Descend to Sea Level at Maximum Rate of Descent for Standard Day With All Engines Operating at Flight Idle Power.

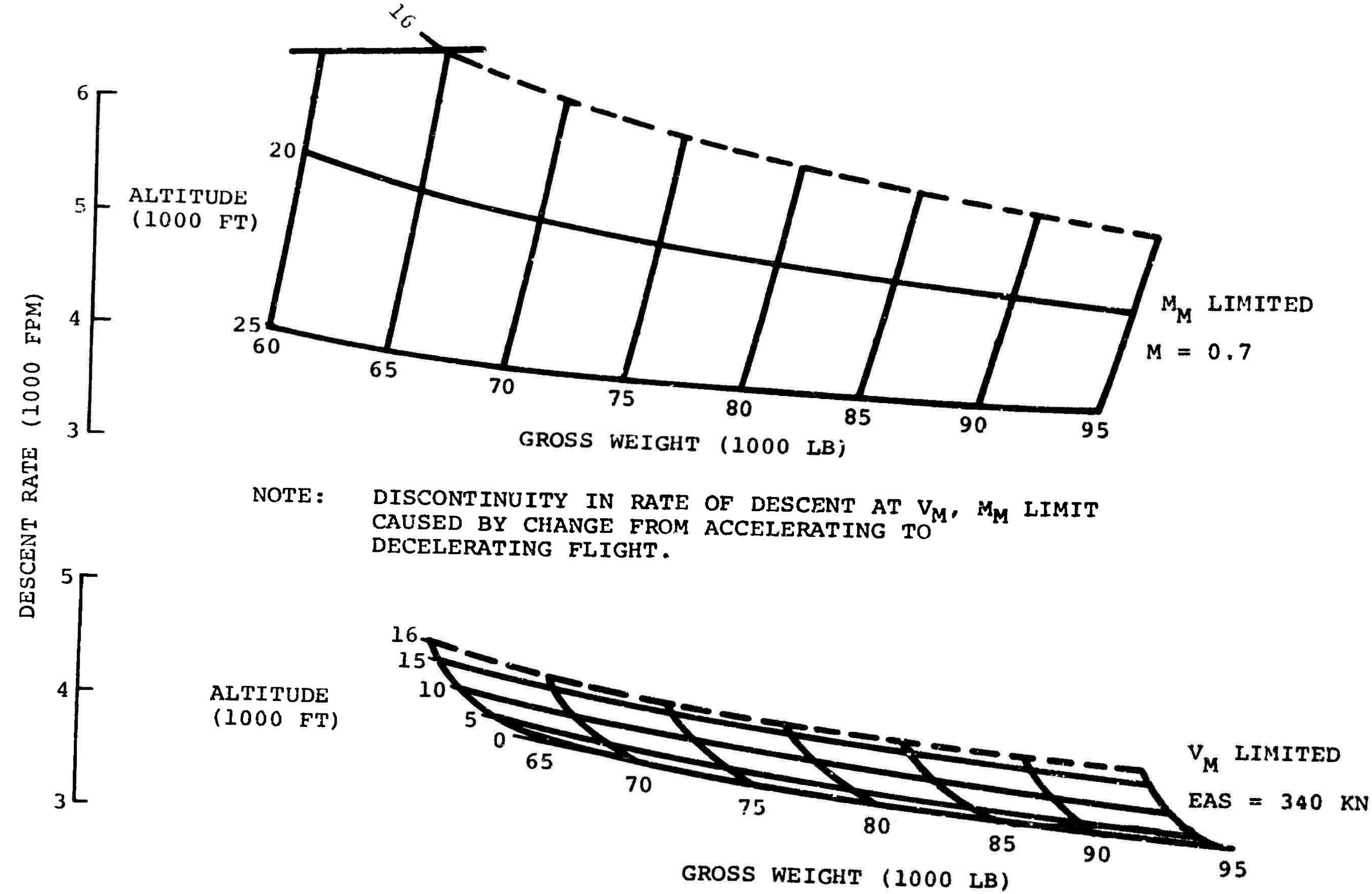


Figure 198. Design Point II Maximum Rate of Descent for Air Force Hot Day With All Engines Operating at Flight Idle Power.

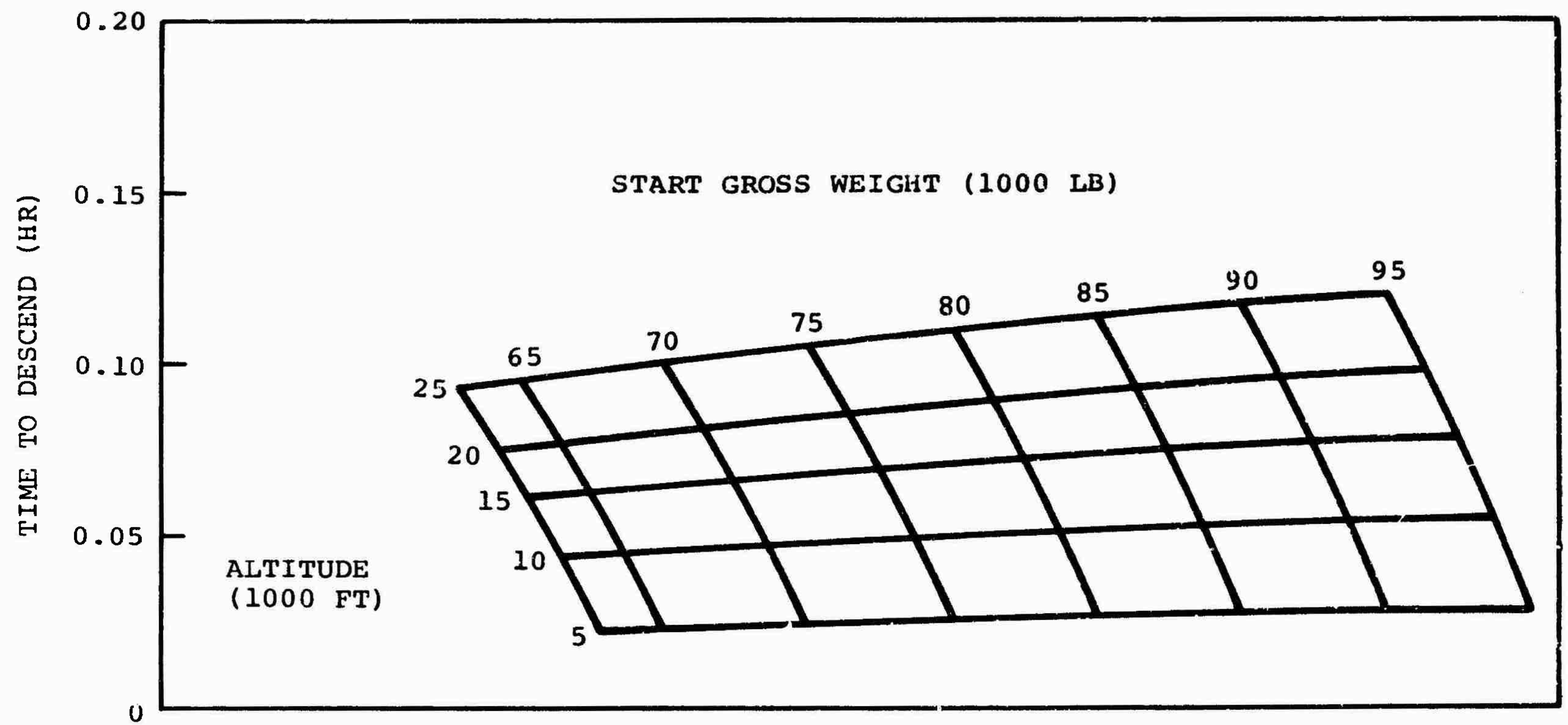


Figure 199. Design Point II Time to Descend to Sea Level at Maximum Rate of Descent for Air Force Hot Day With All Engines Operating at Flight Idle Power.

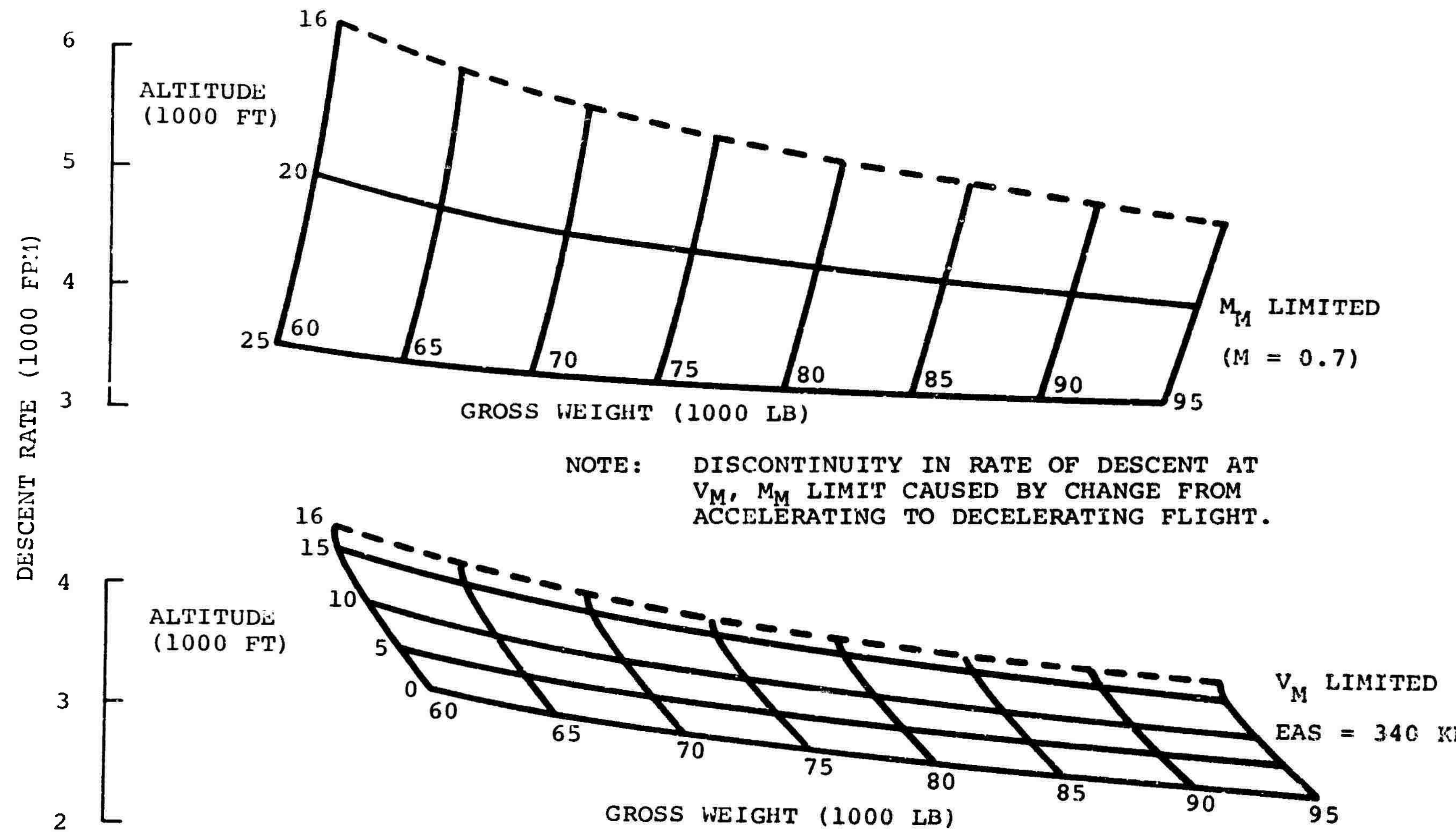


Figure 200. Design Point II Maximum Rate of Descent With Capsule for Standard Day With All Engines Operating at Flight Idle Power.

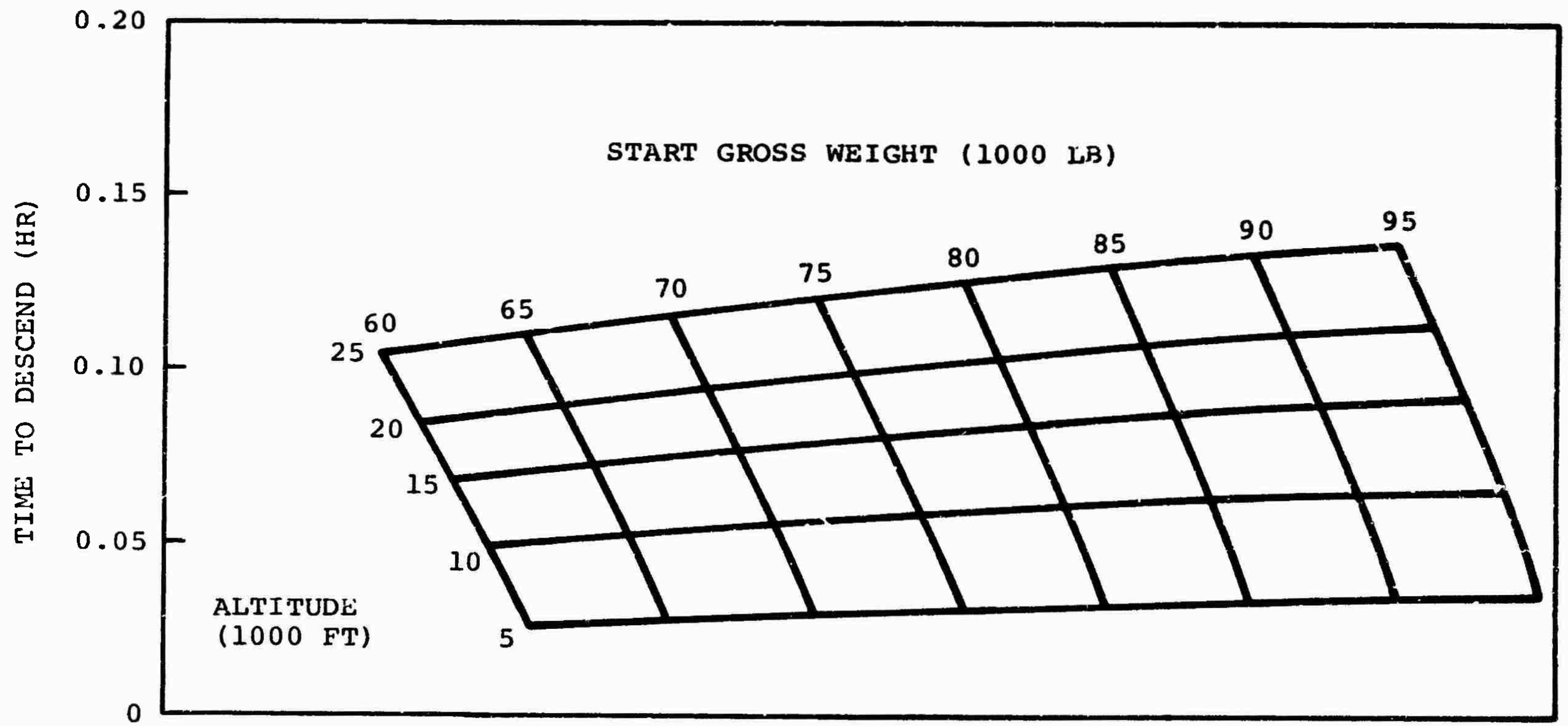
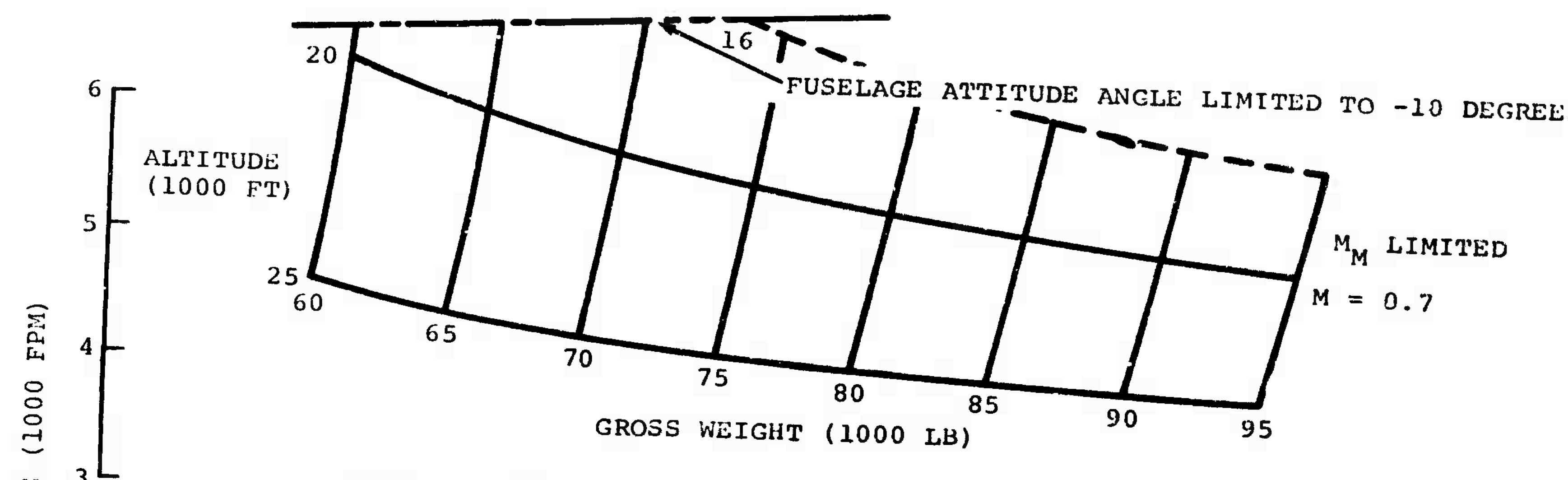


Figure 201. Design Point II Time to Descend to Sea Level With Capsule at Maximum Rate of Descent for Standard Day With All Engines Operating at Flight Idle Power.



NOTE: DISCONTINUITY IN RATE OF DESCENT AT V_M, M_M LIMIT CAUSED BY CHANGE FROM ACCELERATING TO DECELERATING FLIGHT.

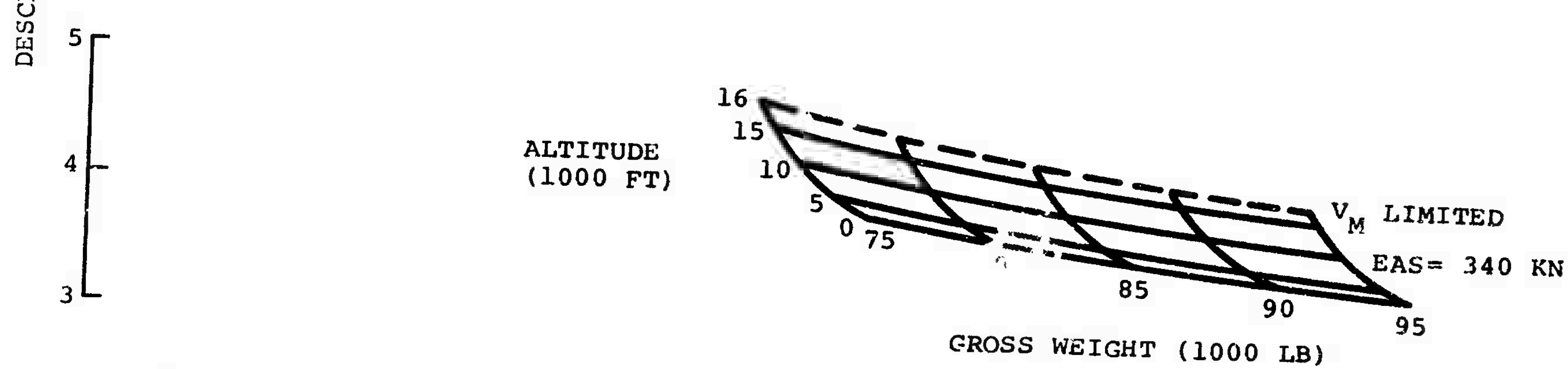


Figure 202. Design Point II Maximum Rate of Descent (With Capsule) for Air Force Hot Day With All Engines Operating at Flight Idle Power.

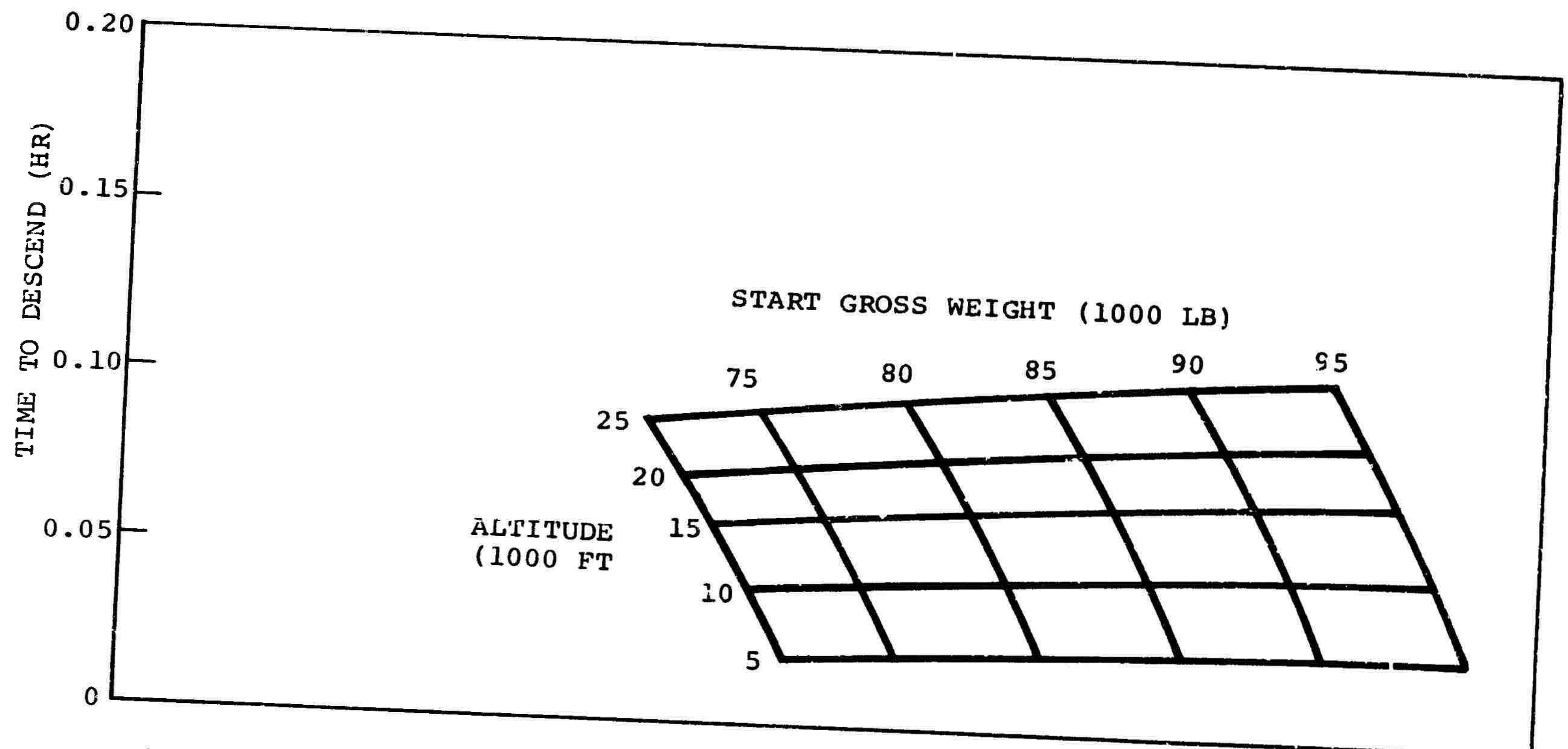


Figure 203. Design Point II Time to Descend With Capsule at Maximum Rate of Descent for Air Force Hot Day With All Engines Operating at Flight Idle Power.

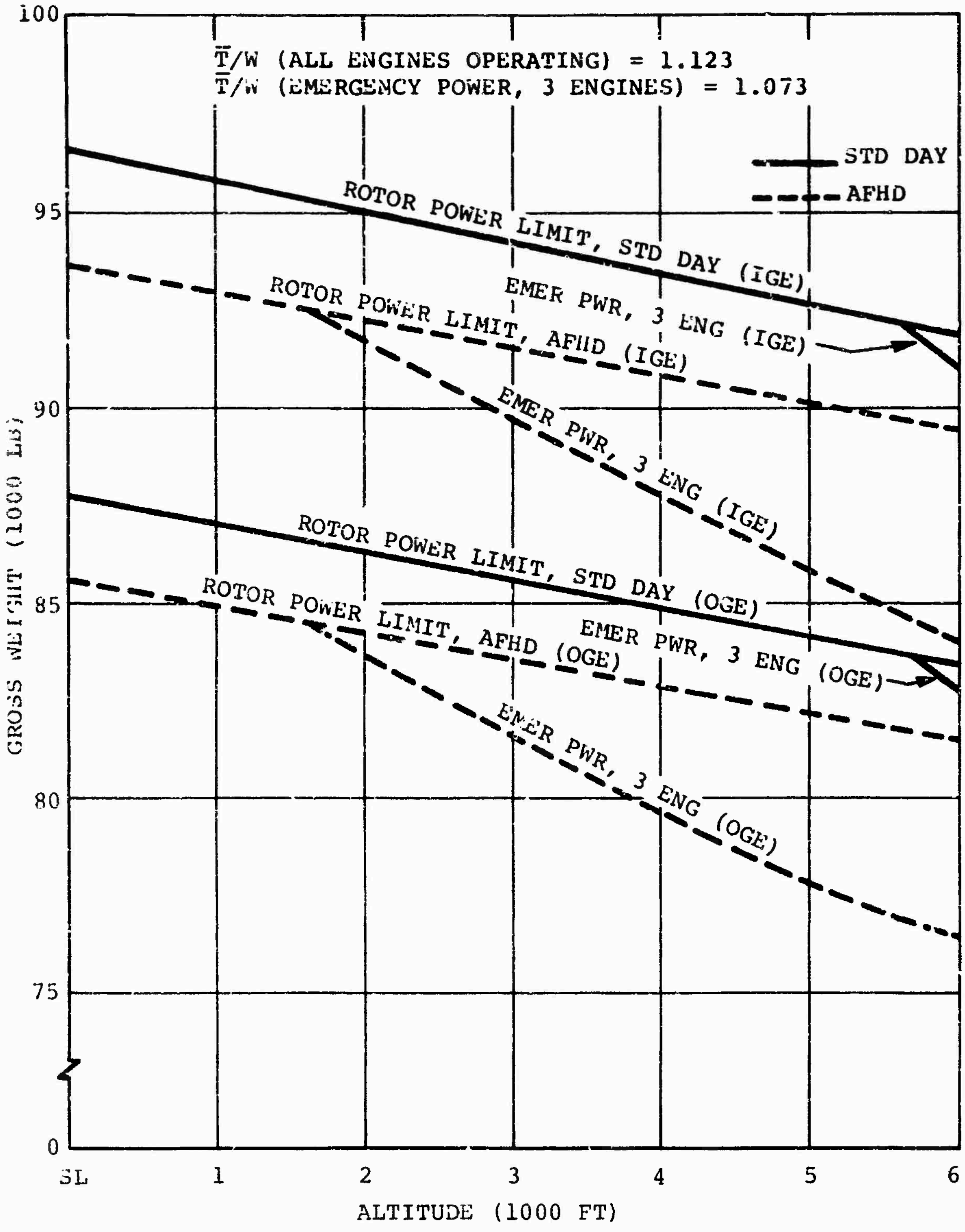


Figure 204. Design Point II Gross Weight Hover Capability Versus Altitude for Standard Day and Air Force Hot Day Conditions.

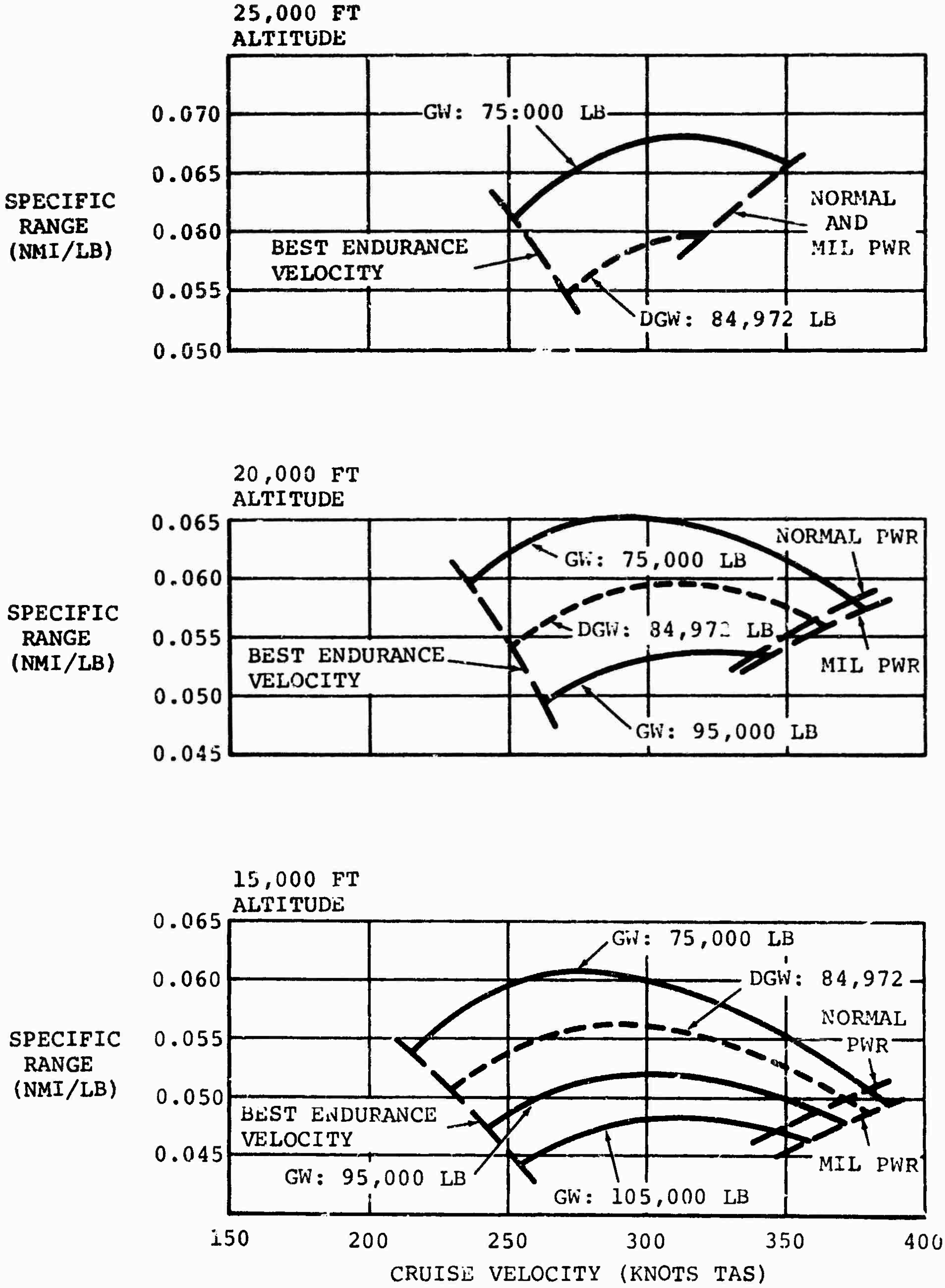


Figure 205. Design Point IV Standard Day Cruise Performance. (Sheet 1 of 2)

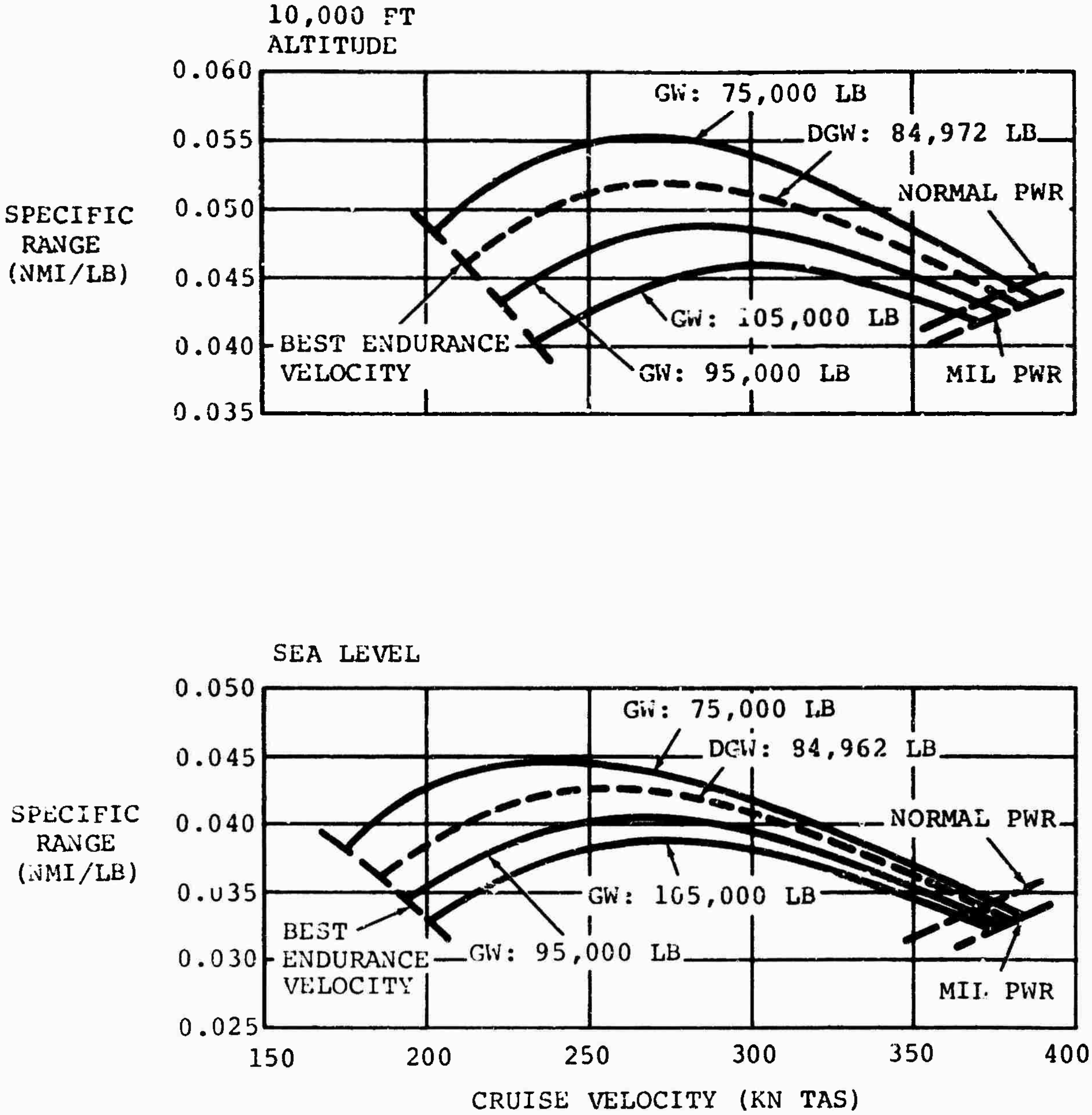


Figure 205. Design Point IV Standard Day Cruise Performance. (Sheet 2 of 2).

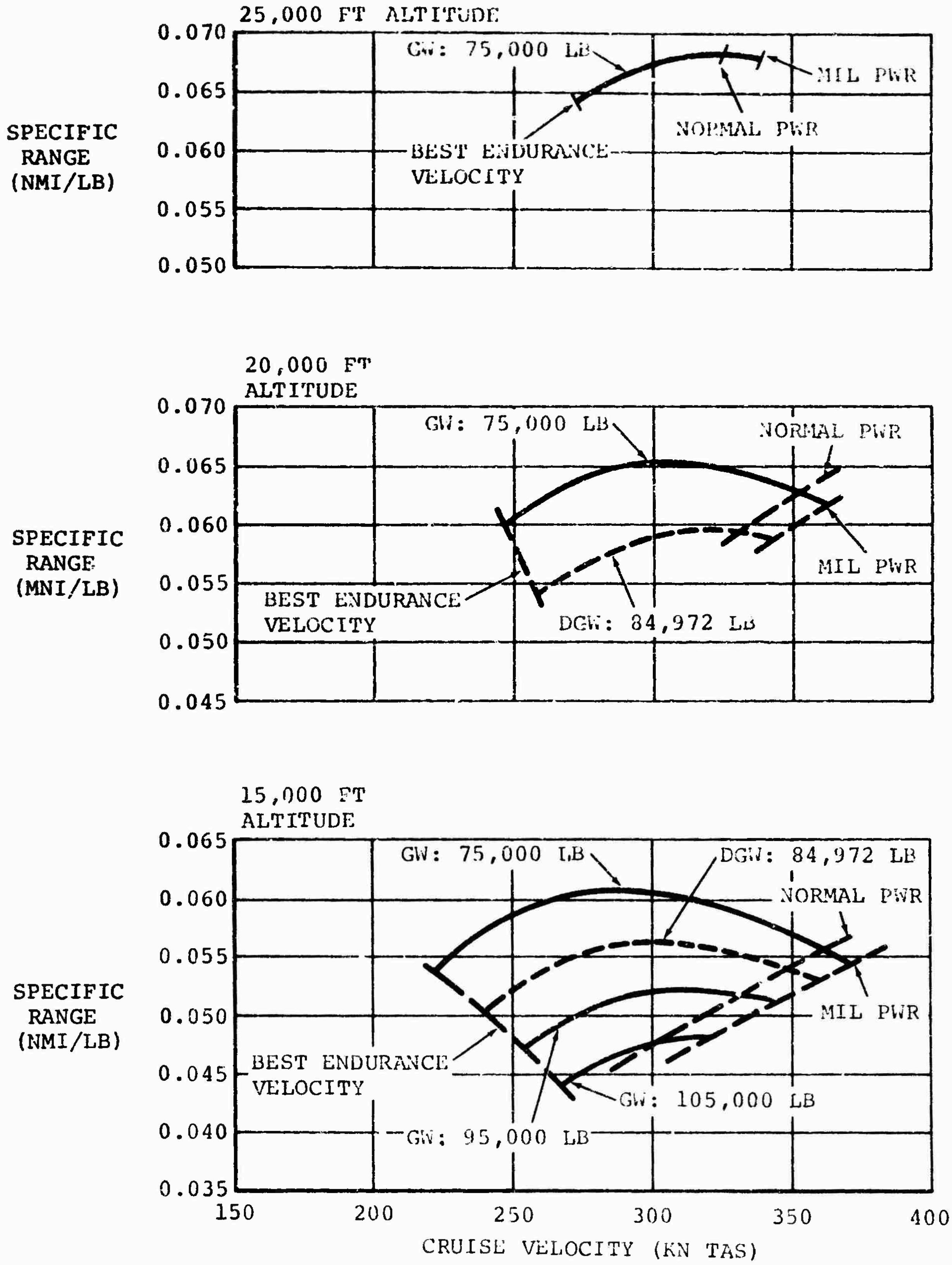
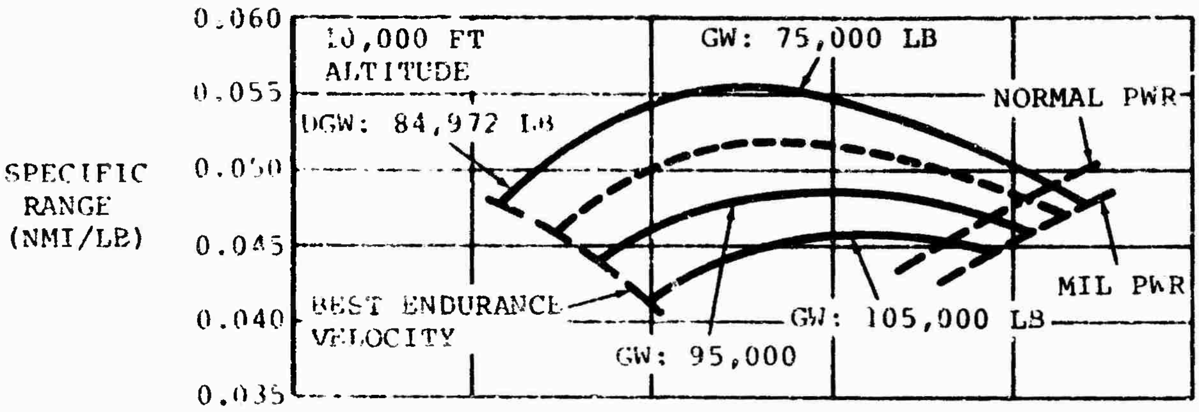


Figure 206. Design Point IV Cruise Performance for Air Force Hot Day (Sheet 1 of 2).



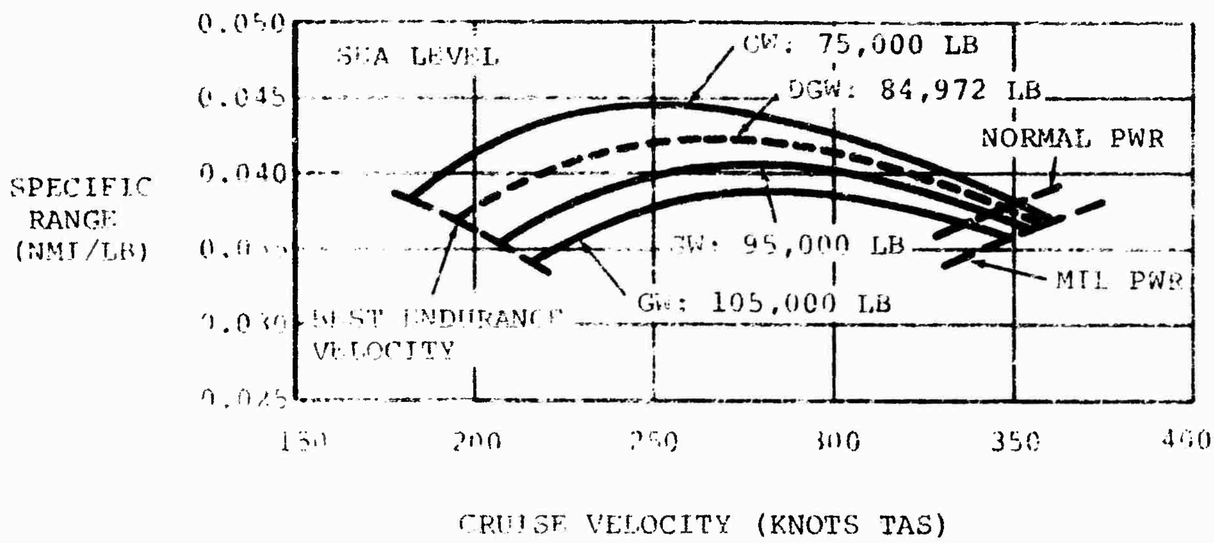


Figure 206. Design Point IV Cruise Performance for Air Force Hot Day. (Sheet 2 of 2).

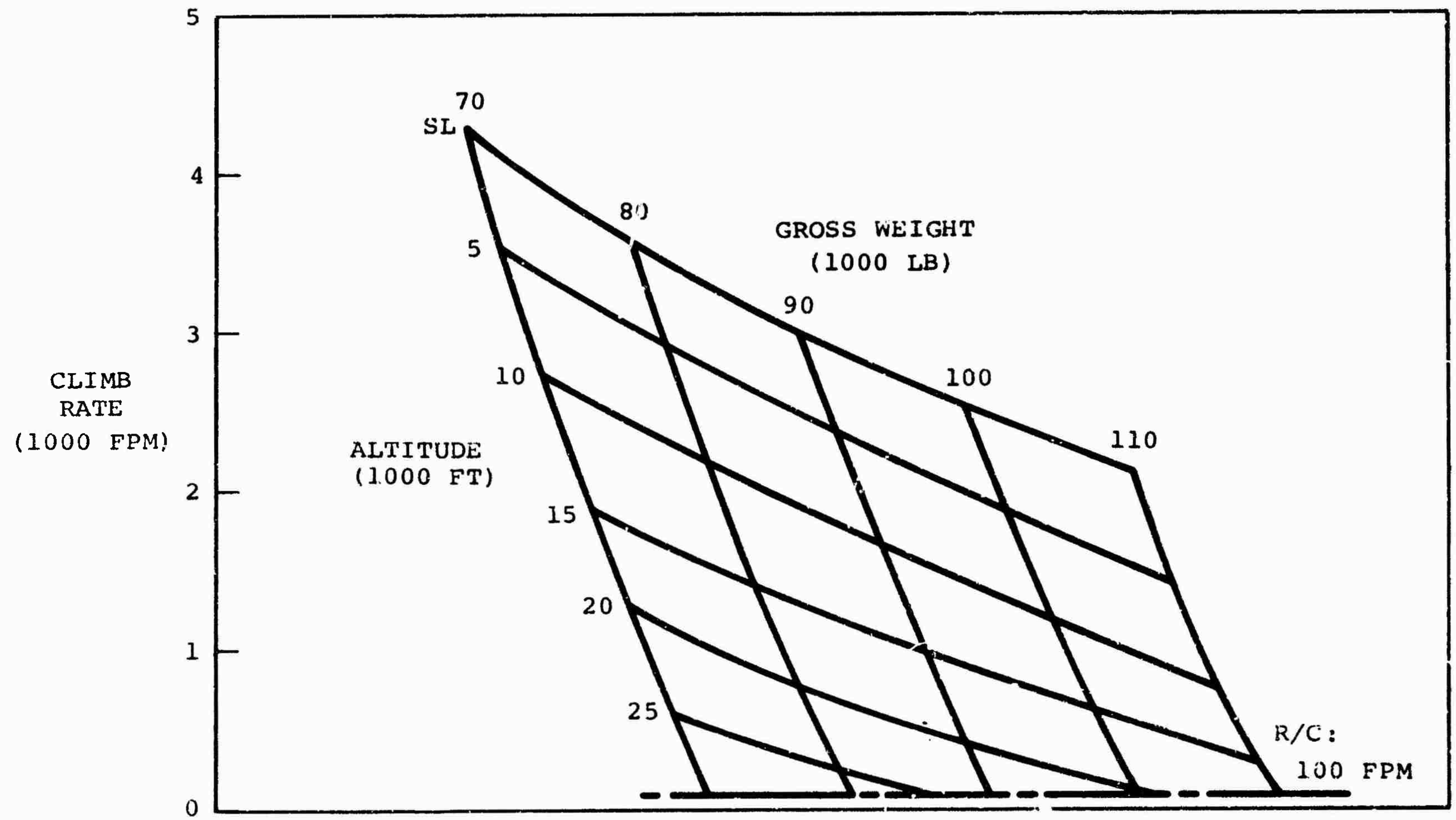


Figure 207. Design Point IV Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

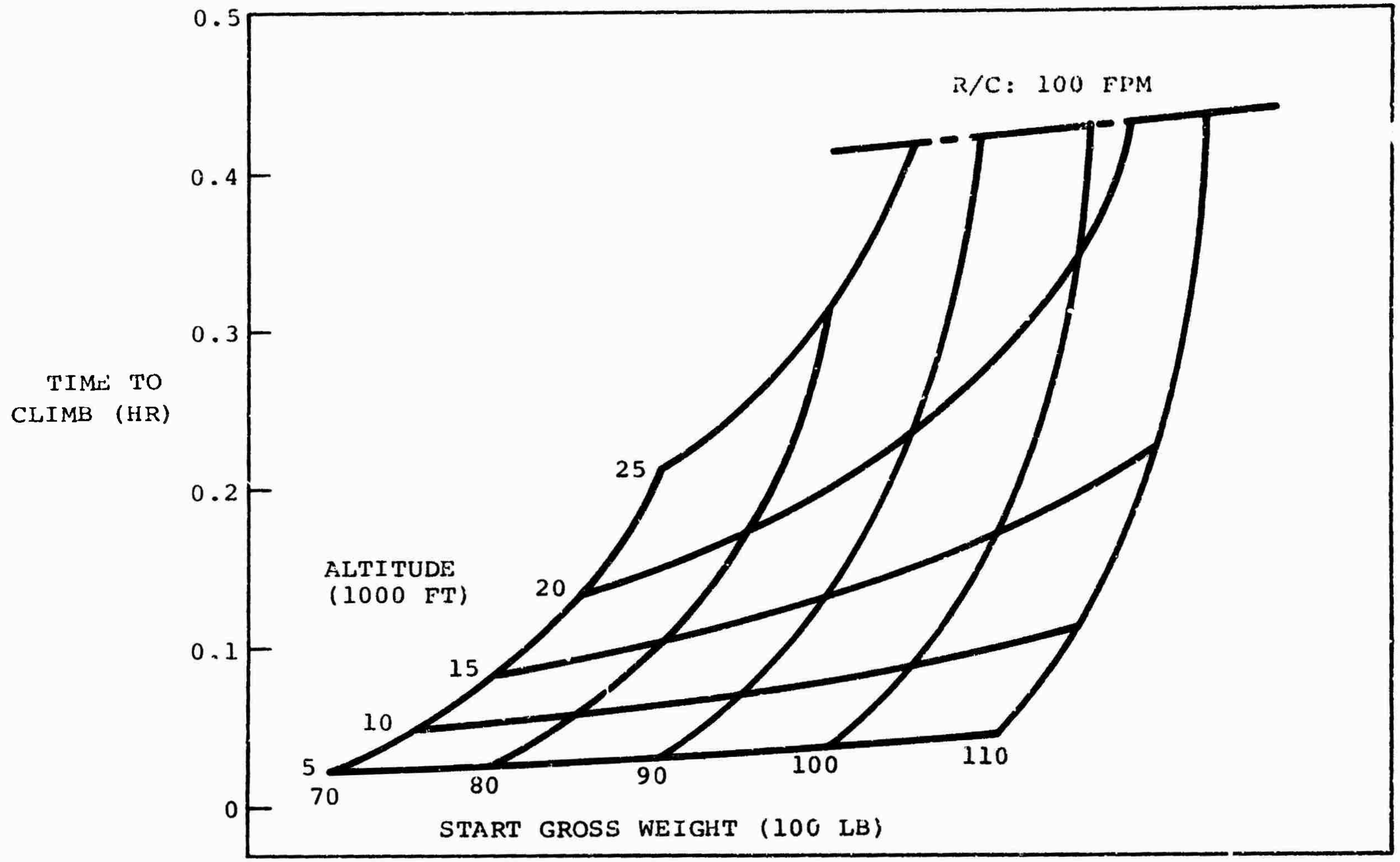


Figure 208. Design Point IV Time to Climb From Sea Level at Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

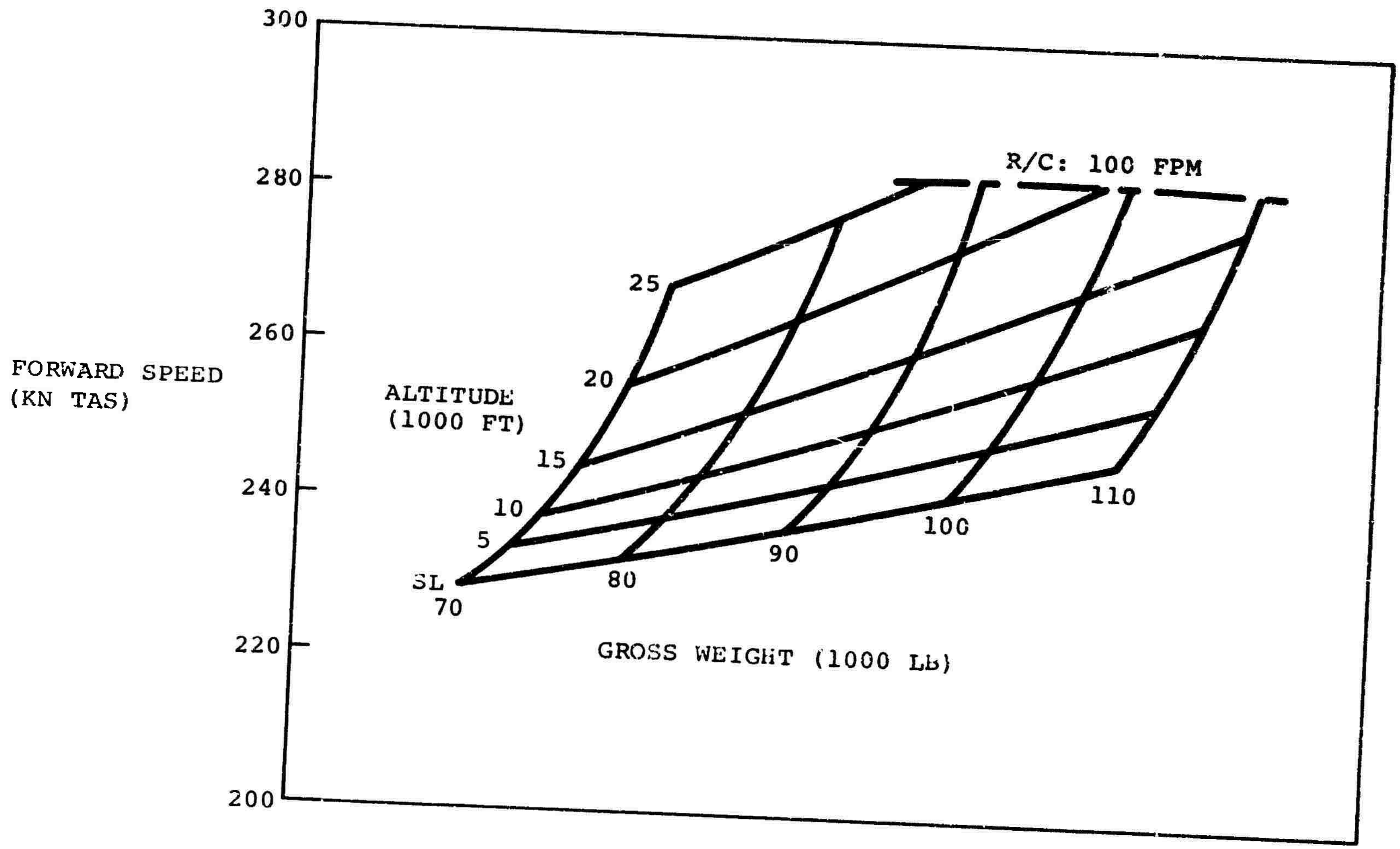


Figure 209. Design Point IV Forward Speed at Maximum Rate of Climb for Standard Day With All Engines Operating at Maximum Power.

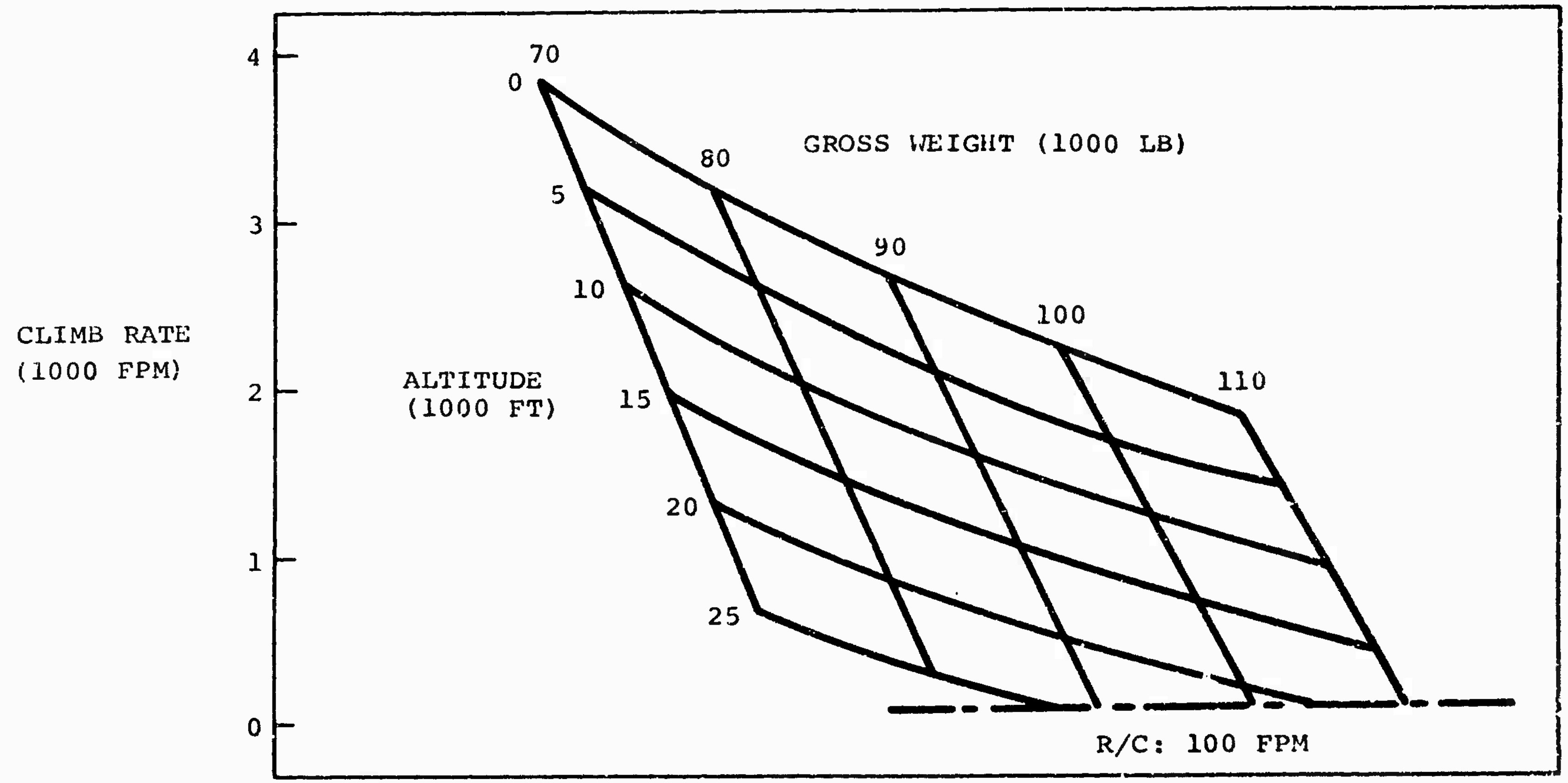


Figure 210. Design Point IV Maximum Rate of Climb for Standard Day With All Engines Operating at Military Power.

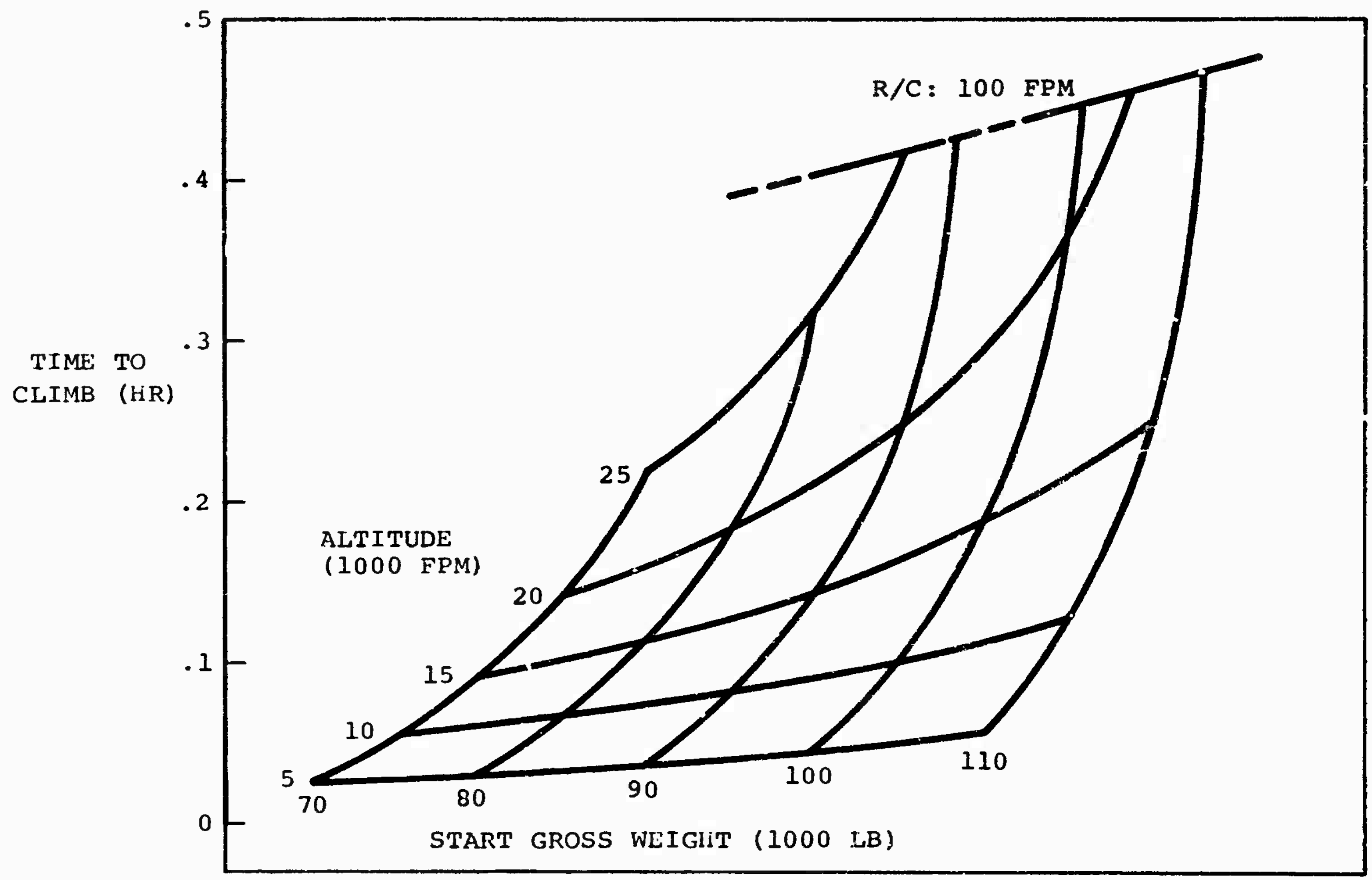


Figure 211. Design Point IV Time to Climb from Sea Level at Maximum Rate of Climb for Standard Day With All Engines Operating at Military Power.

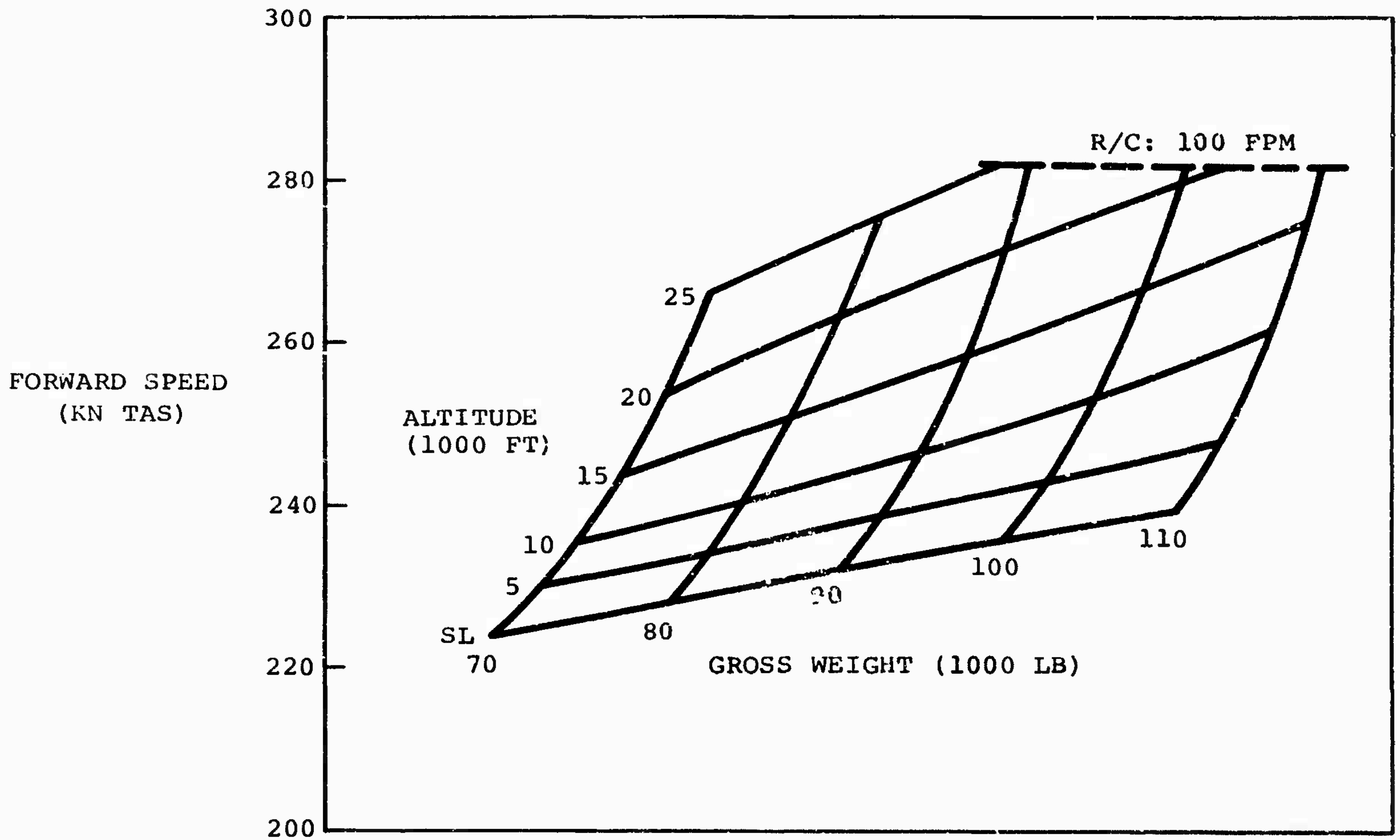


Figure 212. Design Point IV Forward Speed at Maximum Rate of Climb for Standard Day With All Engines Operating at Military Power.

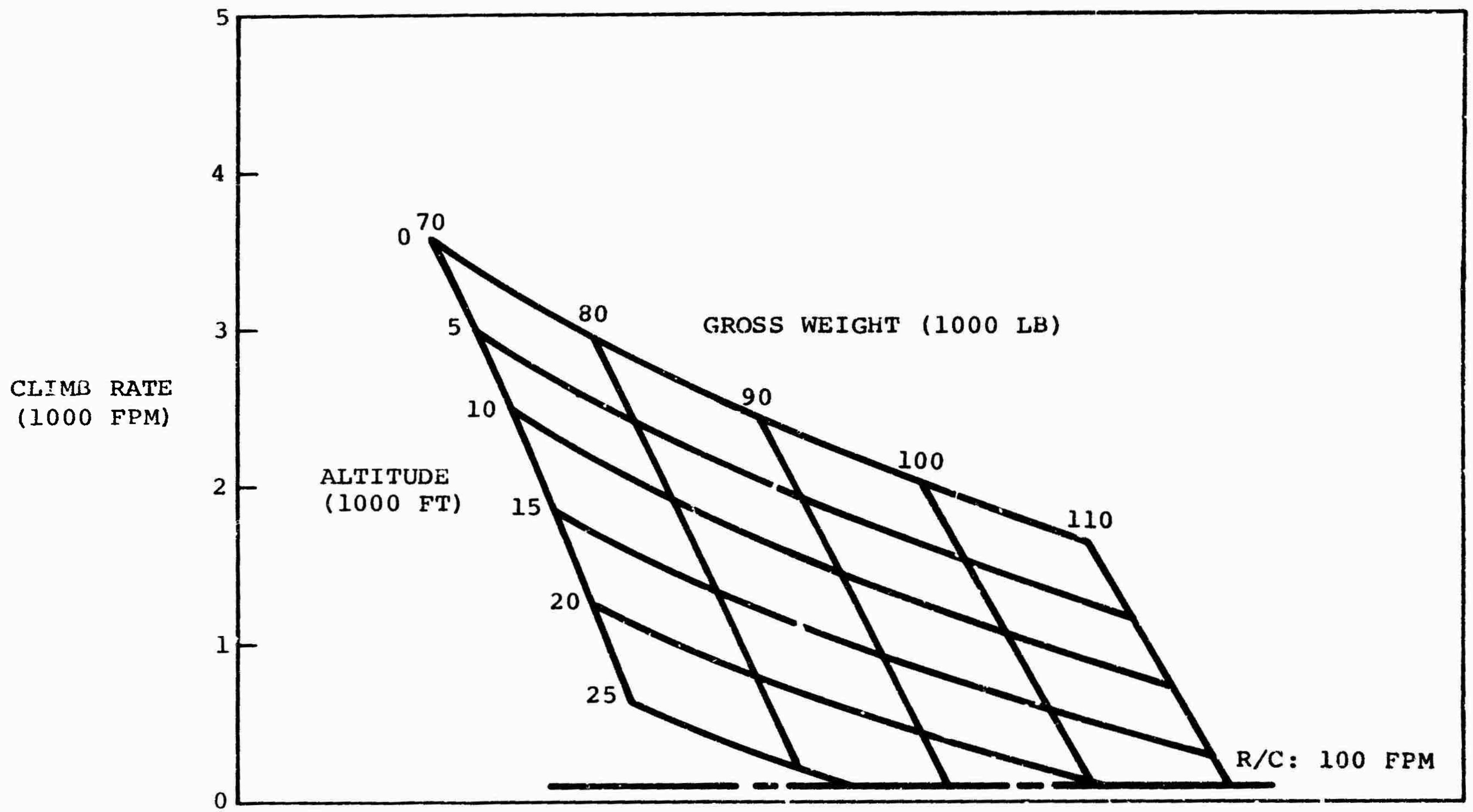


Figure 213. Design Point IV Maximum Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.

Power.

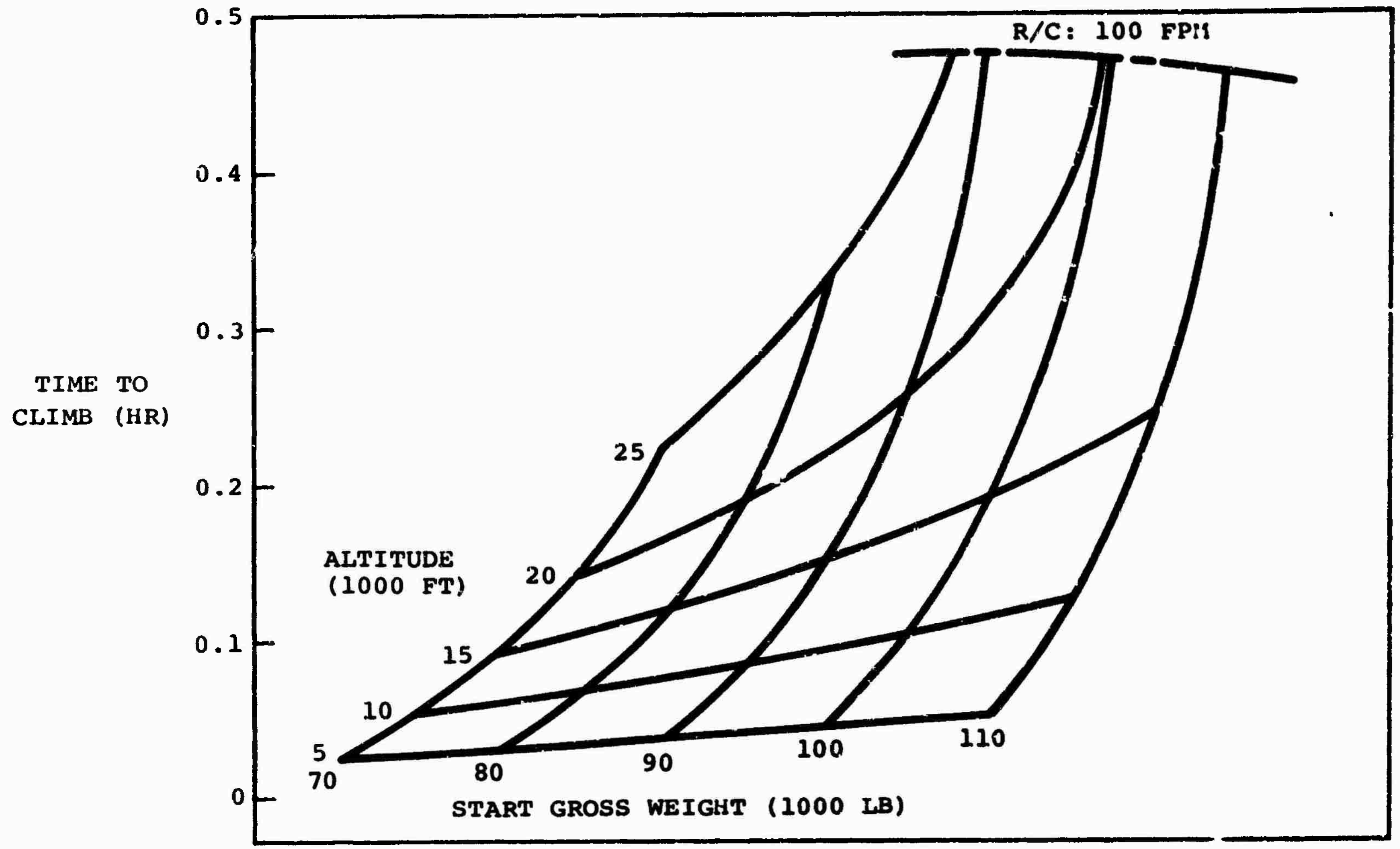


Figure 214. **Design Point IV Time to Climb From Sea Level at Maximum Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.**

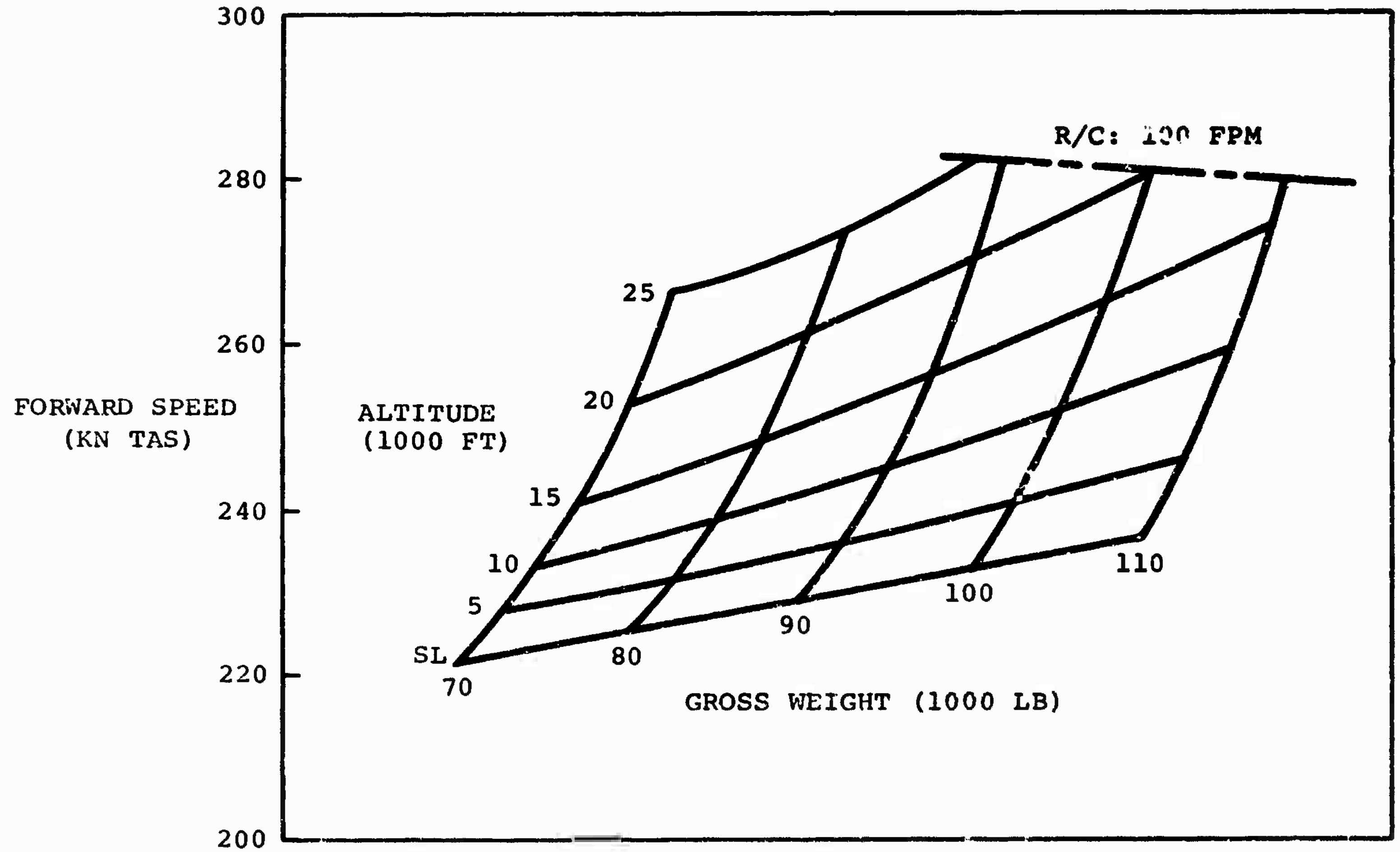


Figure 215. Design Point IV Forward Speed at Maximum Rate of Climb for Standard Day With All Engines Operating at Normal Rated Power.

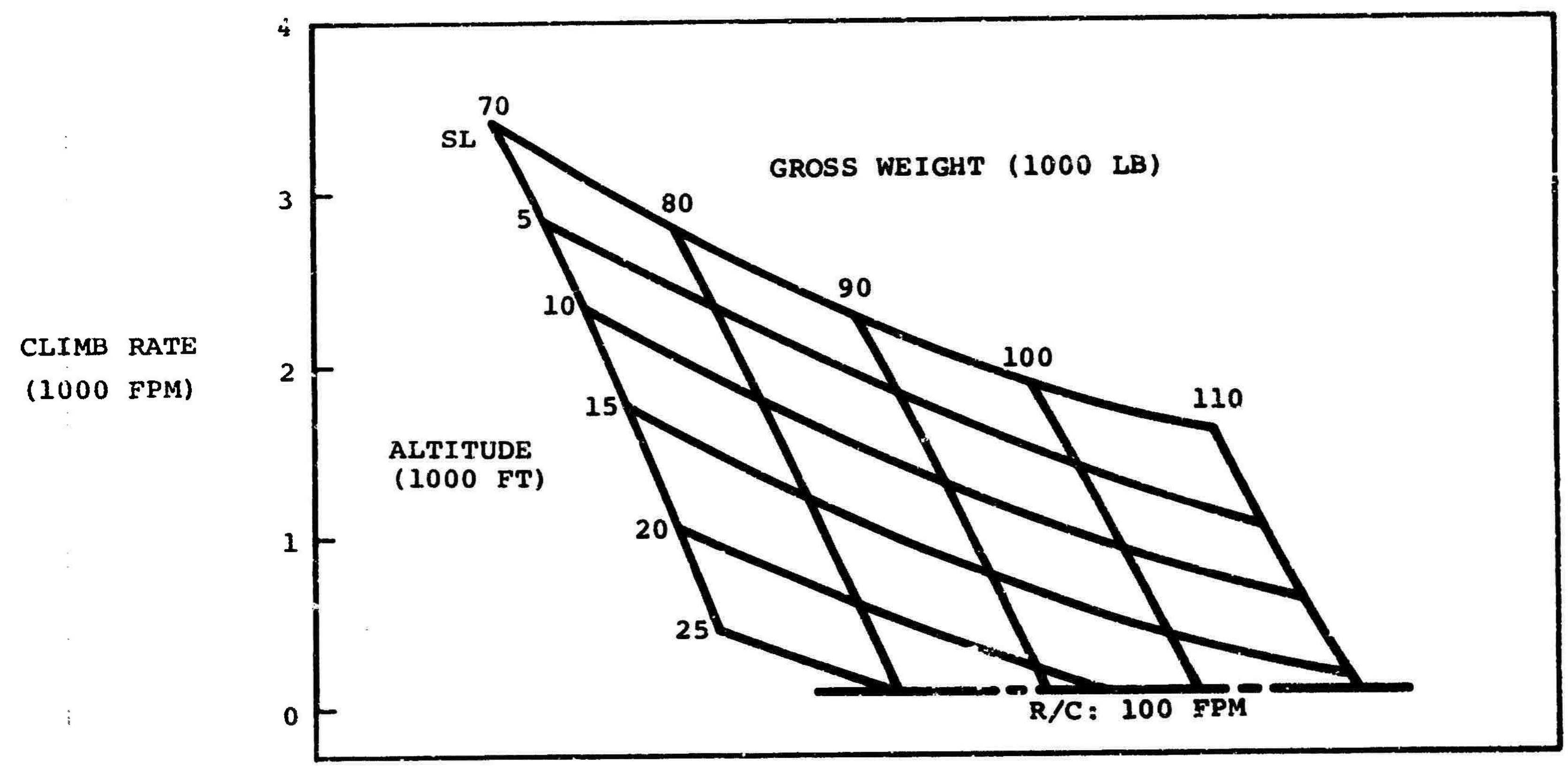


Figure 216. Design Point IV Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

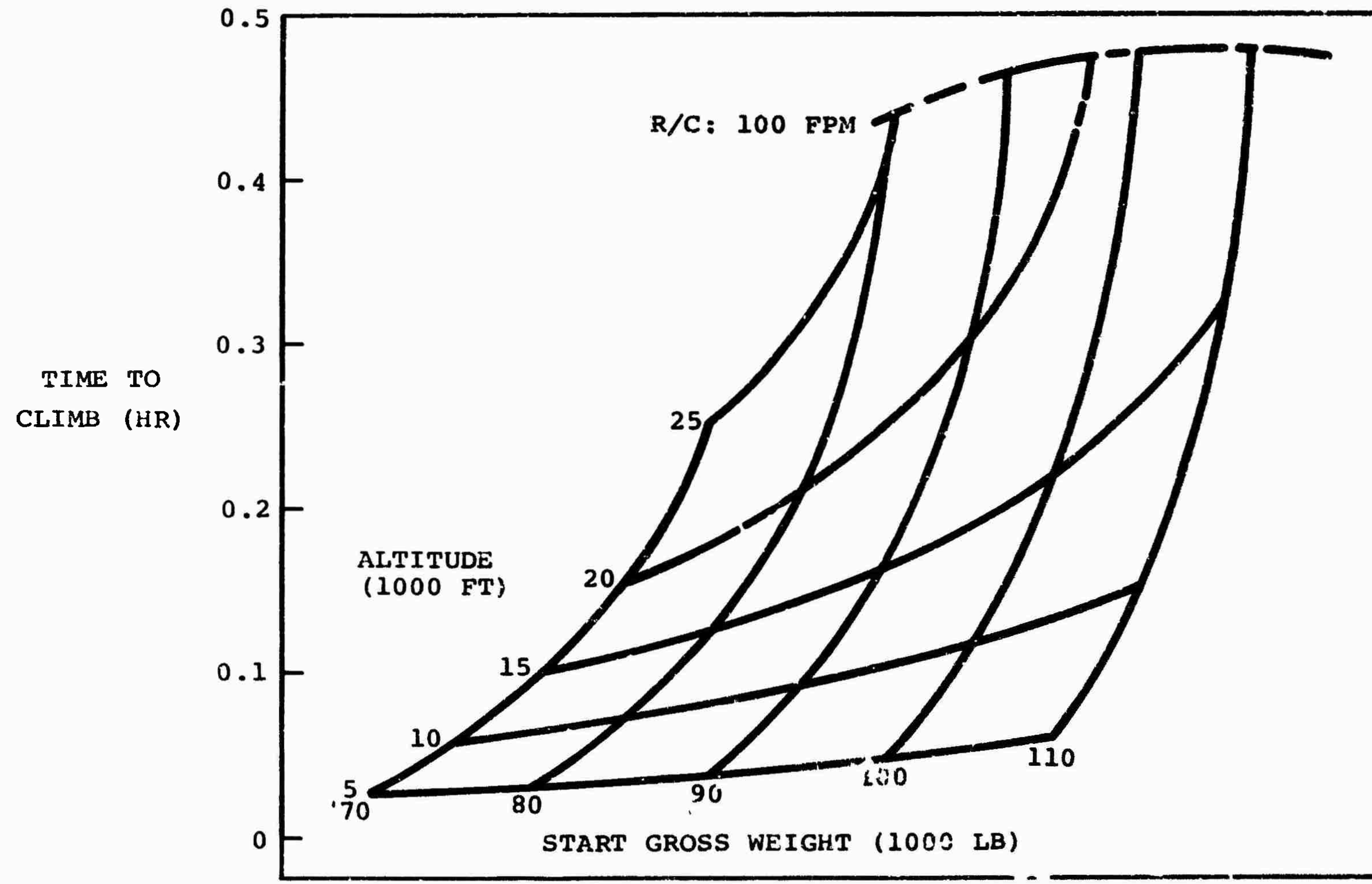


Figure 217. Design Point IV Time to Climb From Sea Level at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

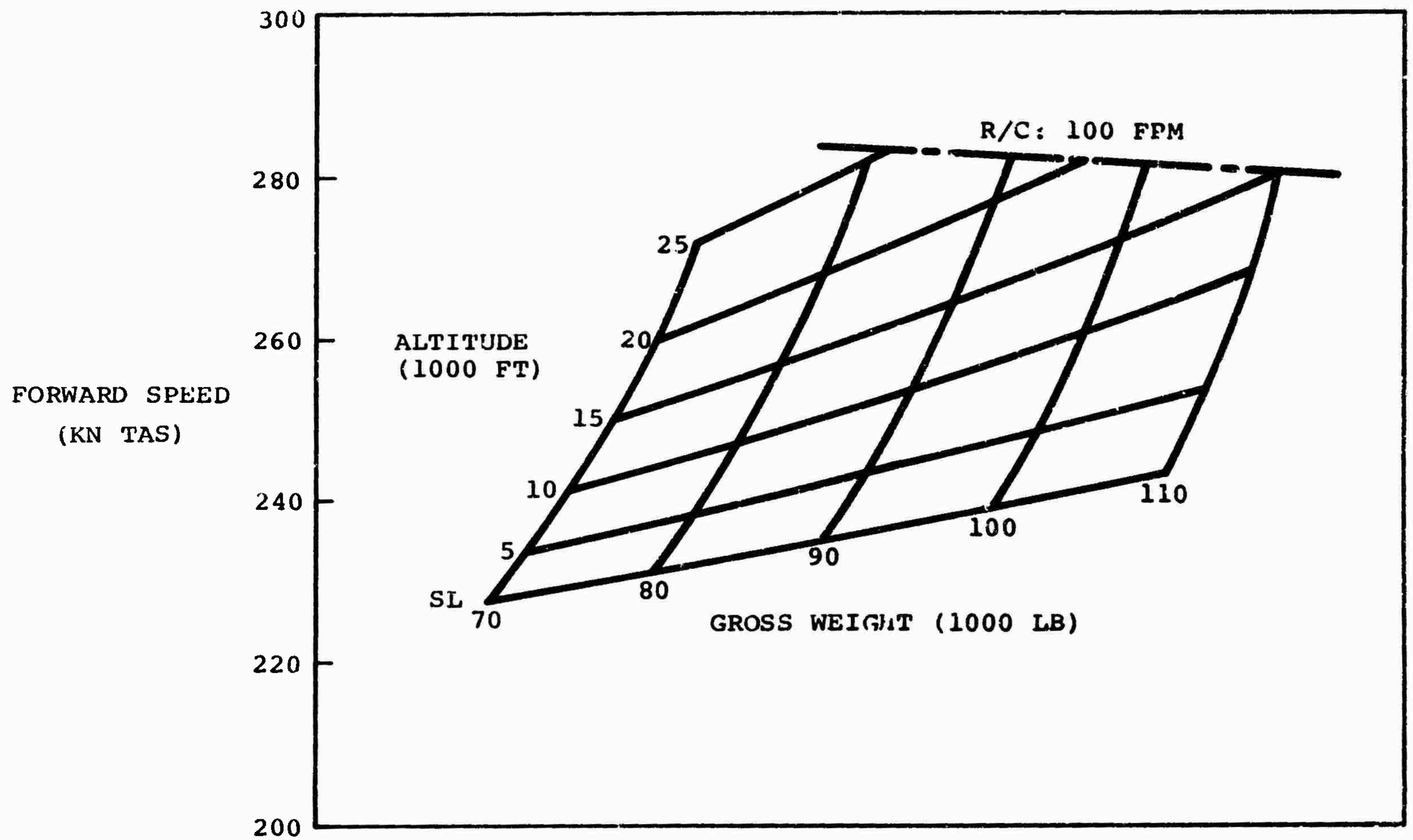


Figure 218. Design Point IV Forward Speed at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Maximum Power.

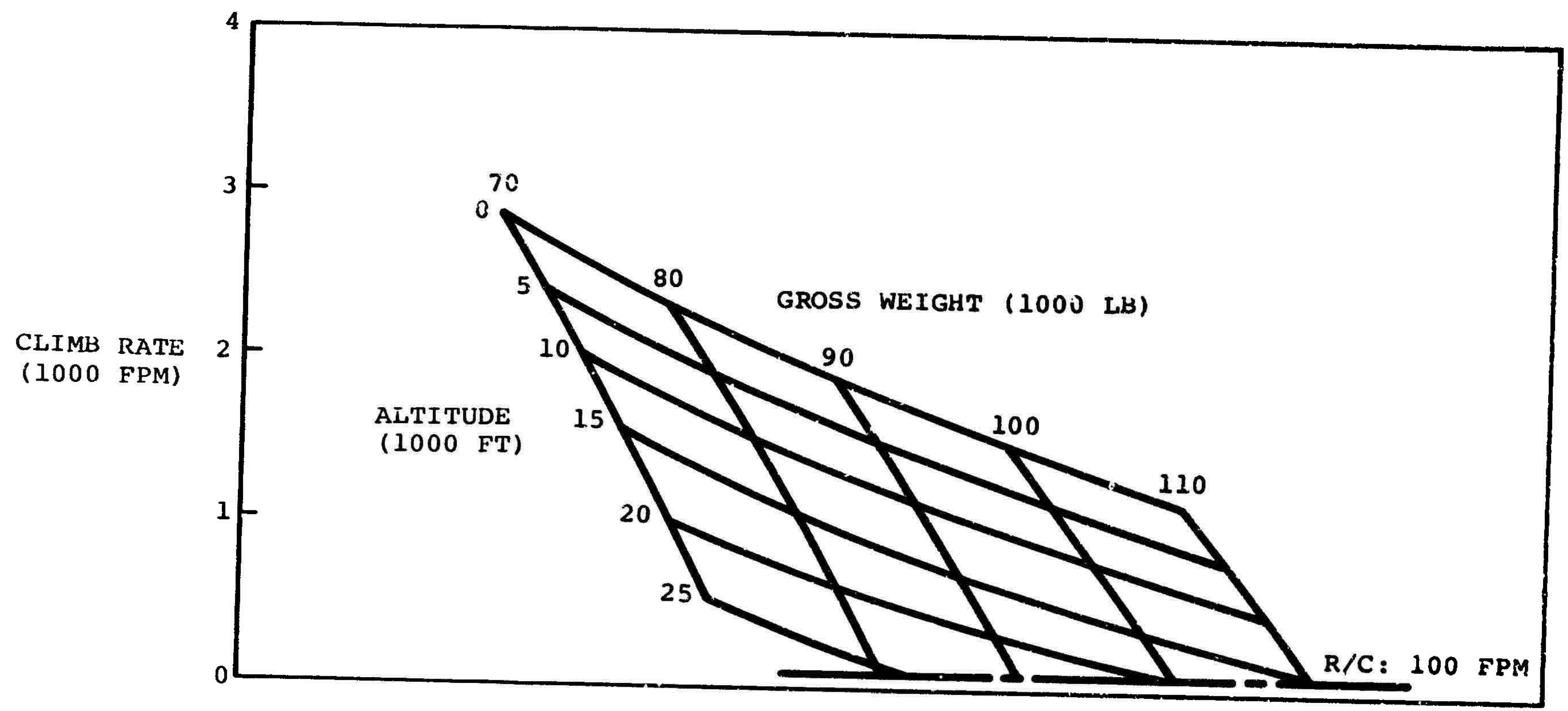


Figure 219. Design Point IV Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

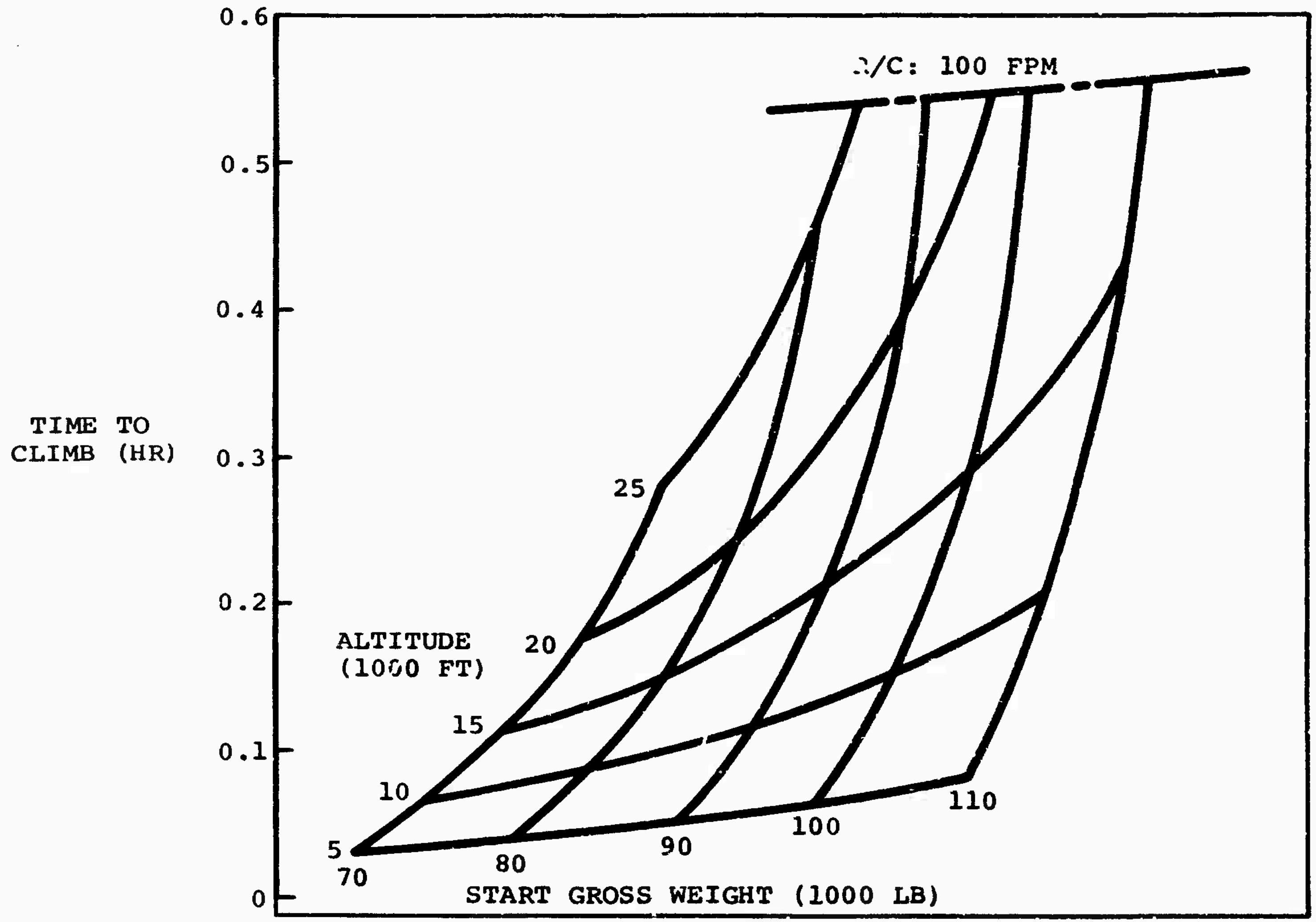


Figure 220. Design Point IV Time to Climb From Sea Level at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

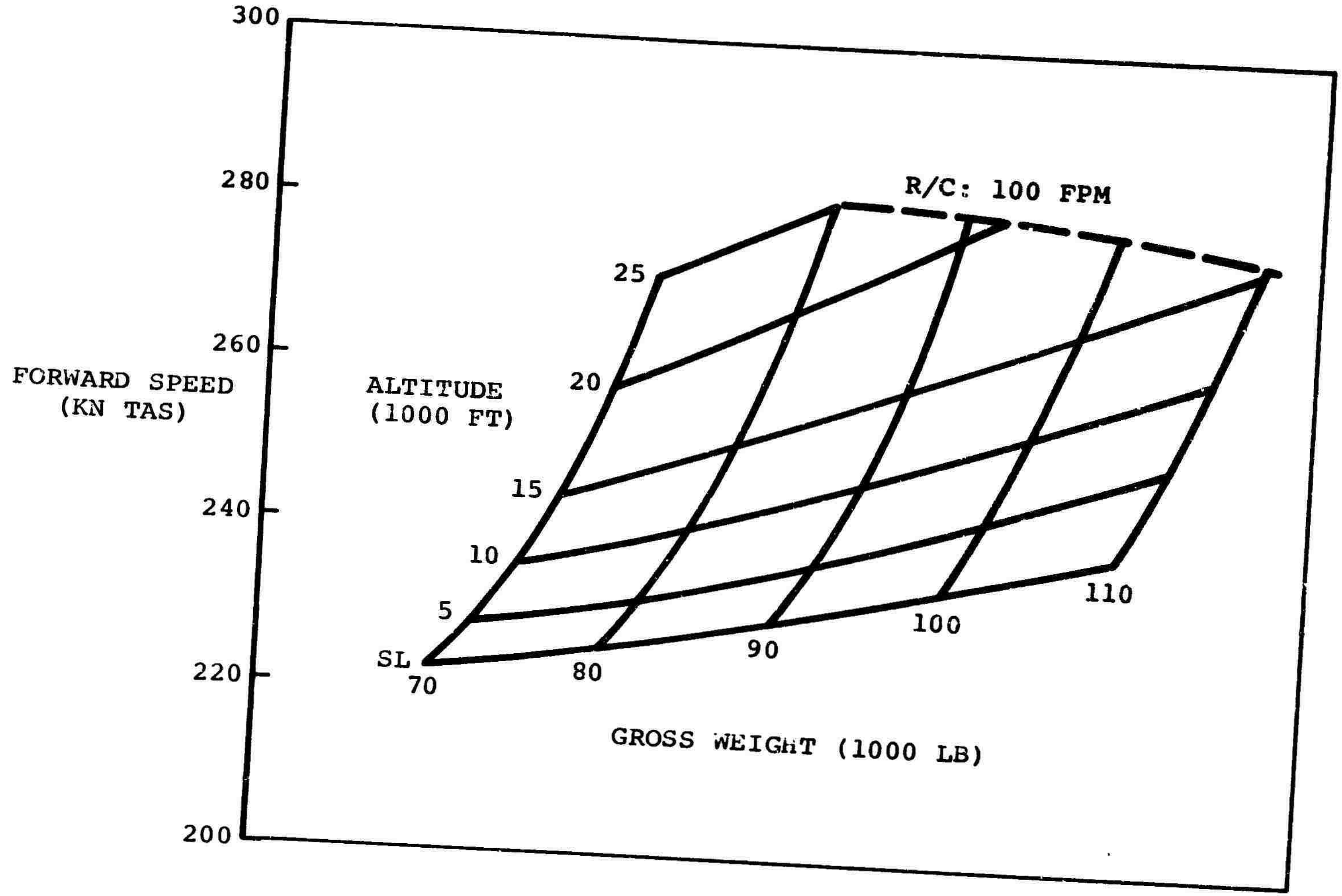


Figure 221. Design Point IV Forward Speed at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Military Power.

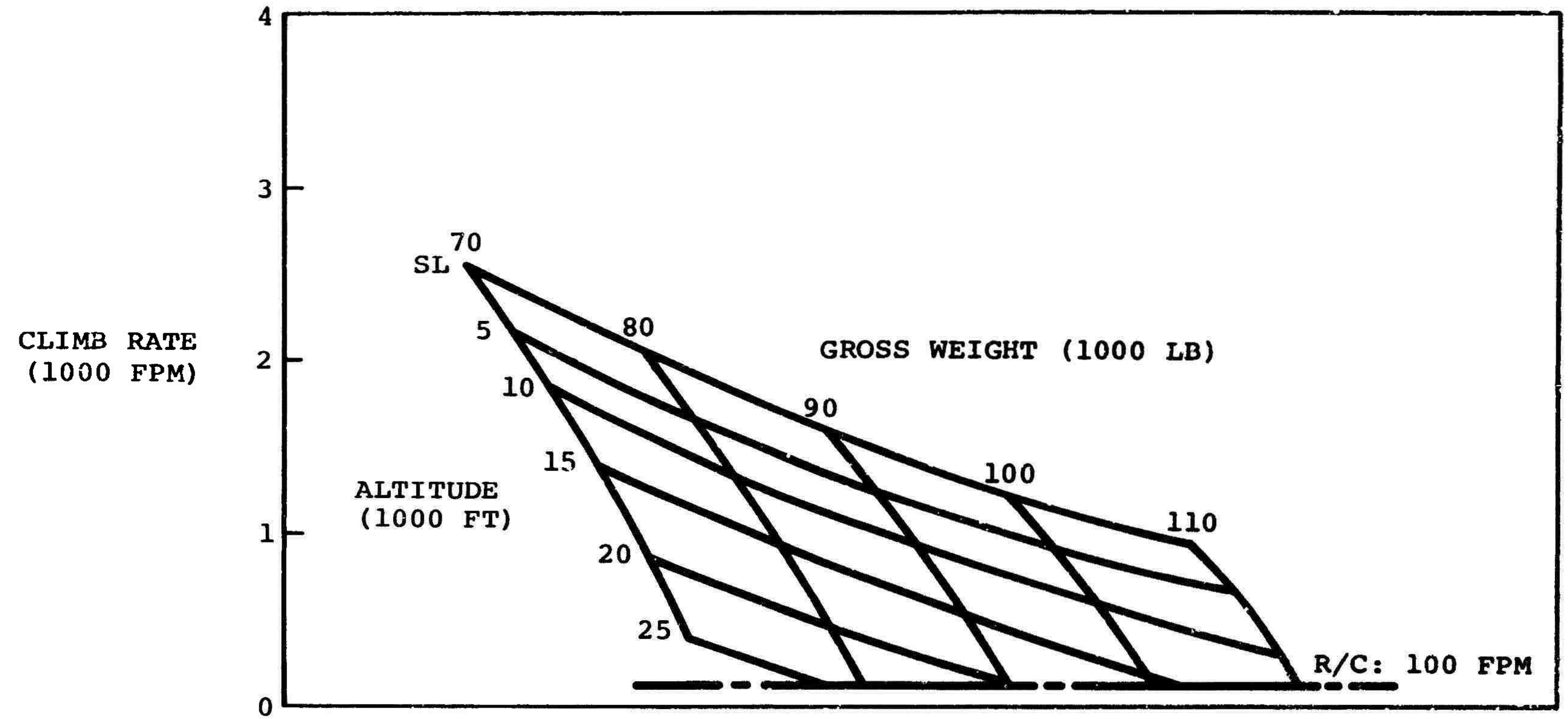


Figure 222. Design Point IV Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

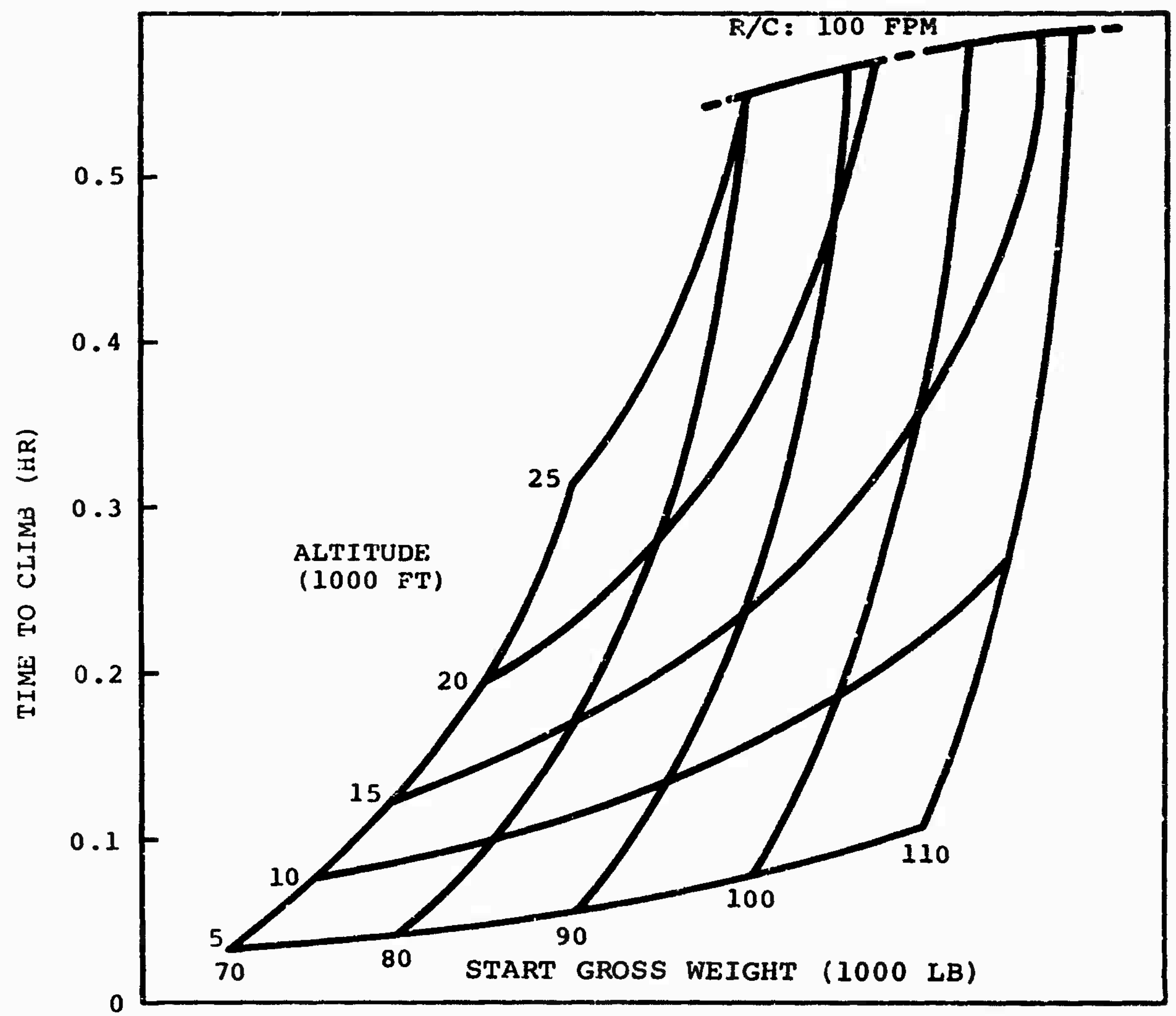


Figure 223. Design Point IV Time to Climb From Sea Level at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

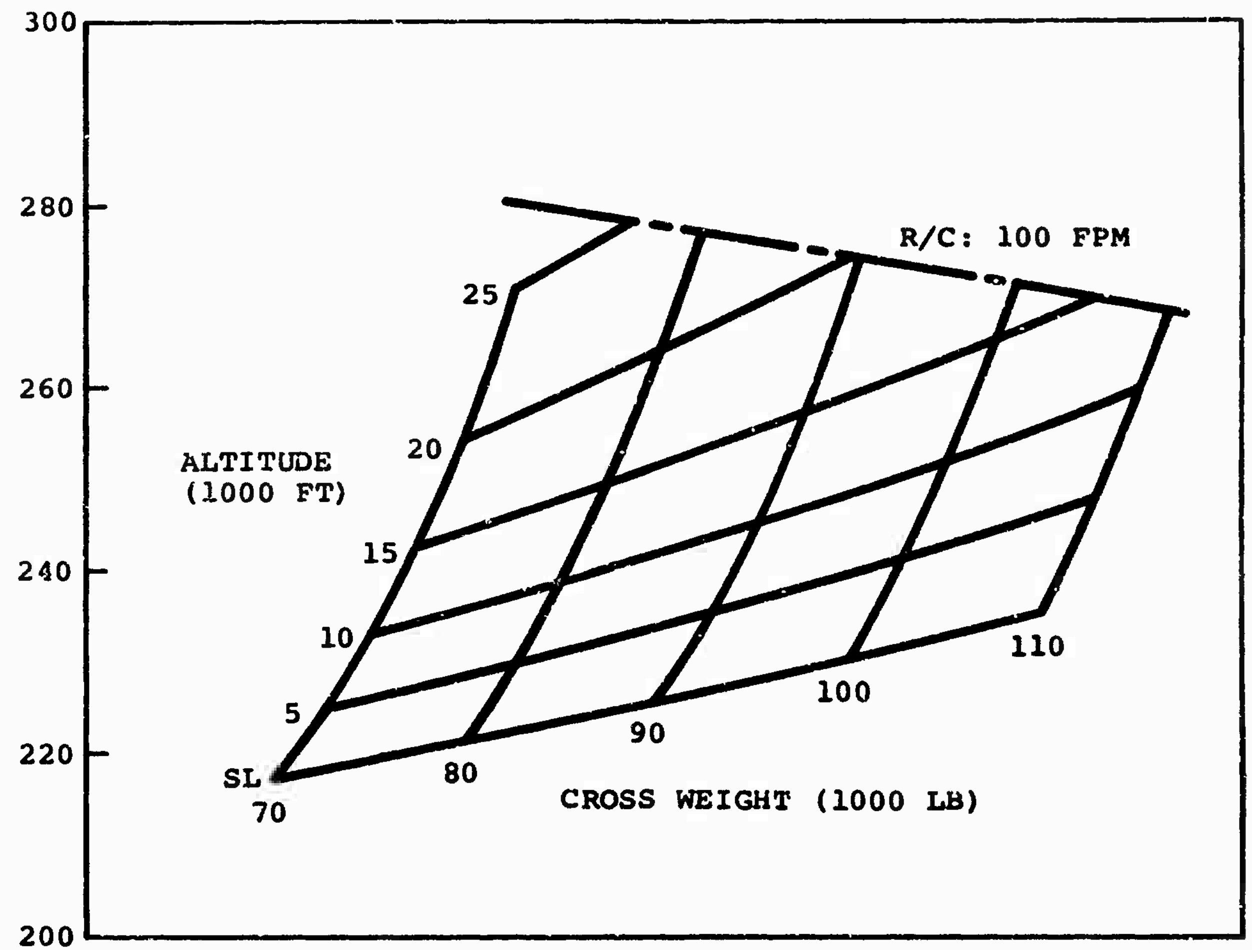


Figure 224. Design Point IV Forward Speed at Maximum Rate of Climb for Air Force Hot Day With All Engines Operating at Normal Rated Power.

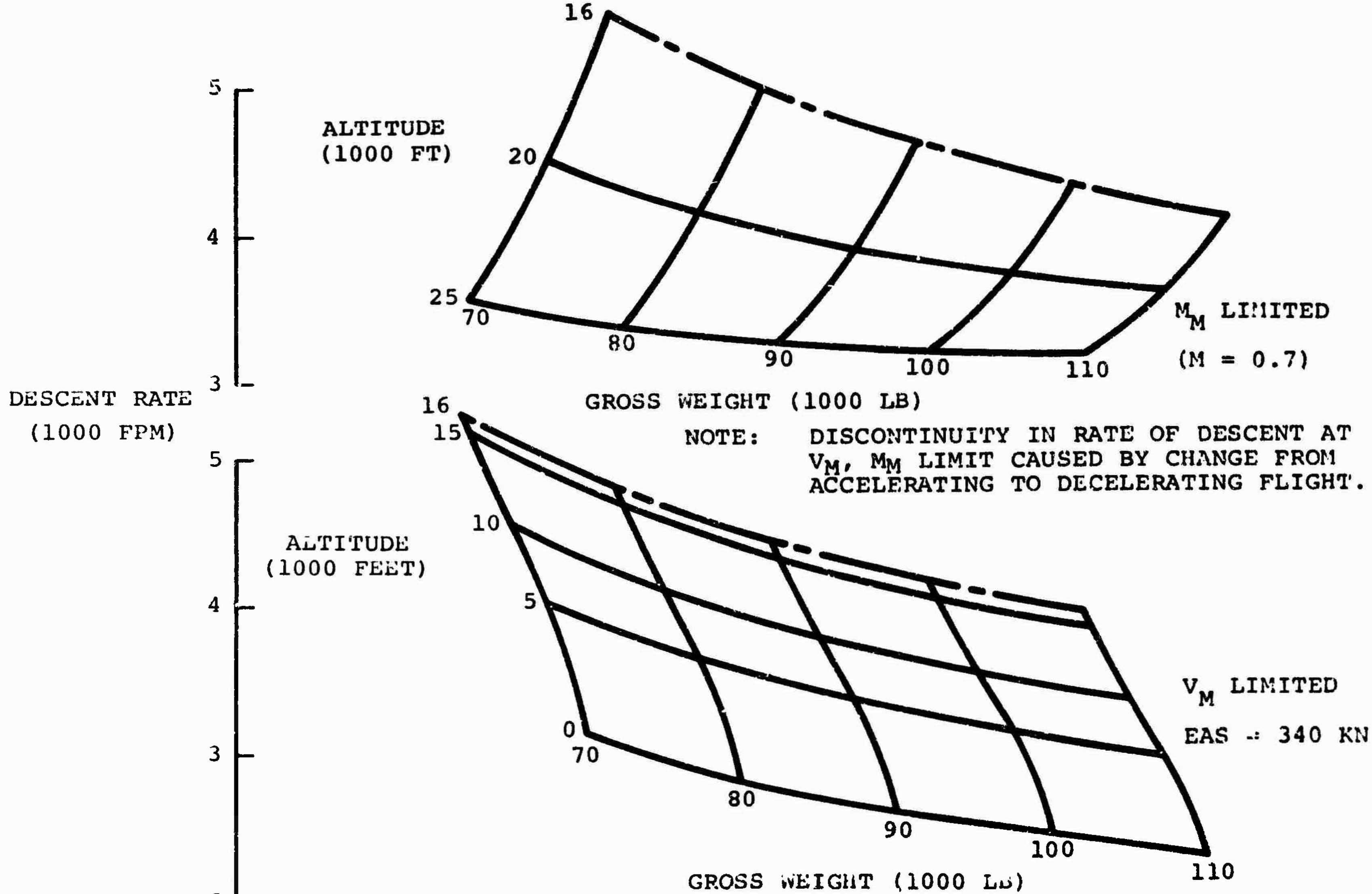


Figure 225. Design Point IV Maximum Rate of Descent for Standard Day With All Engines Operating at Flight Idle Power.

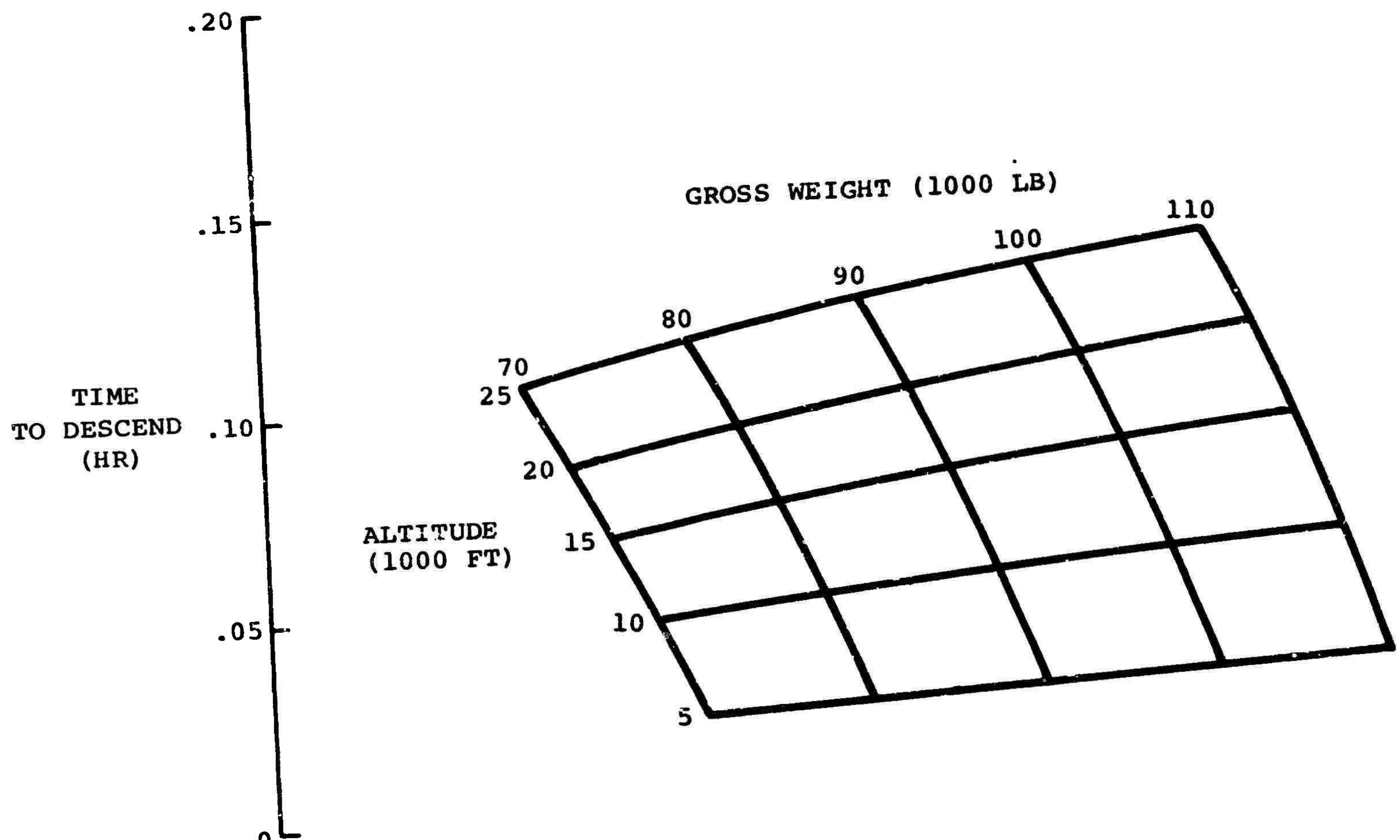


Figure 226. Design Point IV Time to Descend to Sea Level at Maximum Rate of Descent for Standard Day With All Engines Operating at Flight Idle Power.

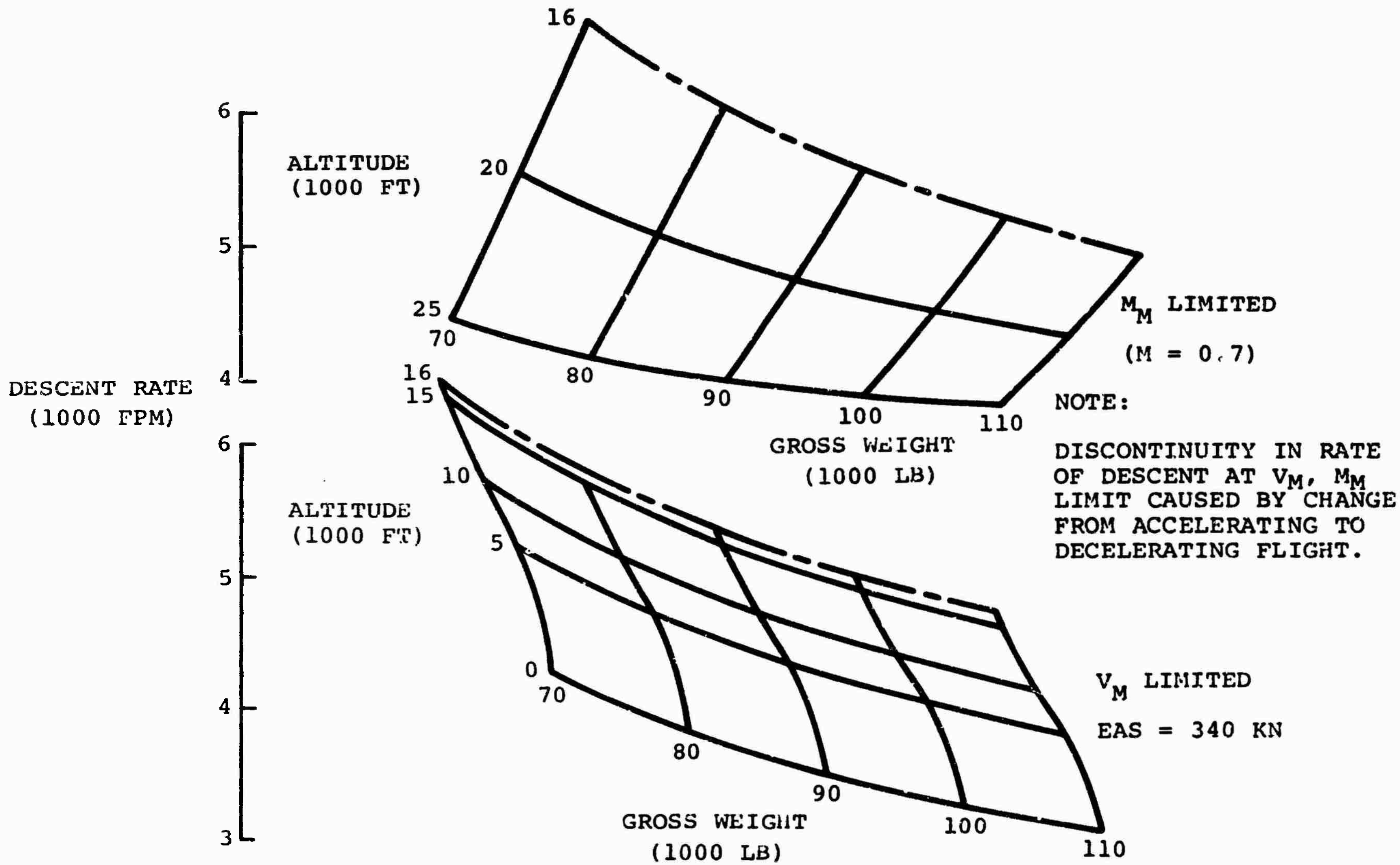


Figure 227. Design Point IV Maximum Rate of Descent for Air Force Hot Day With All Engines Operating at Flight Idle Power.

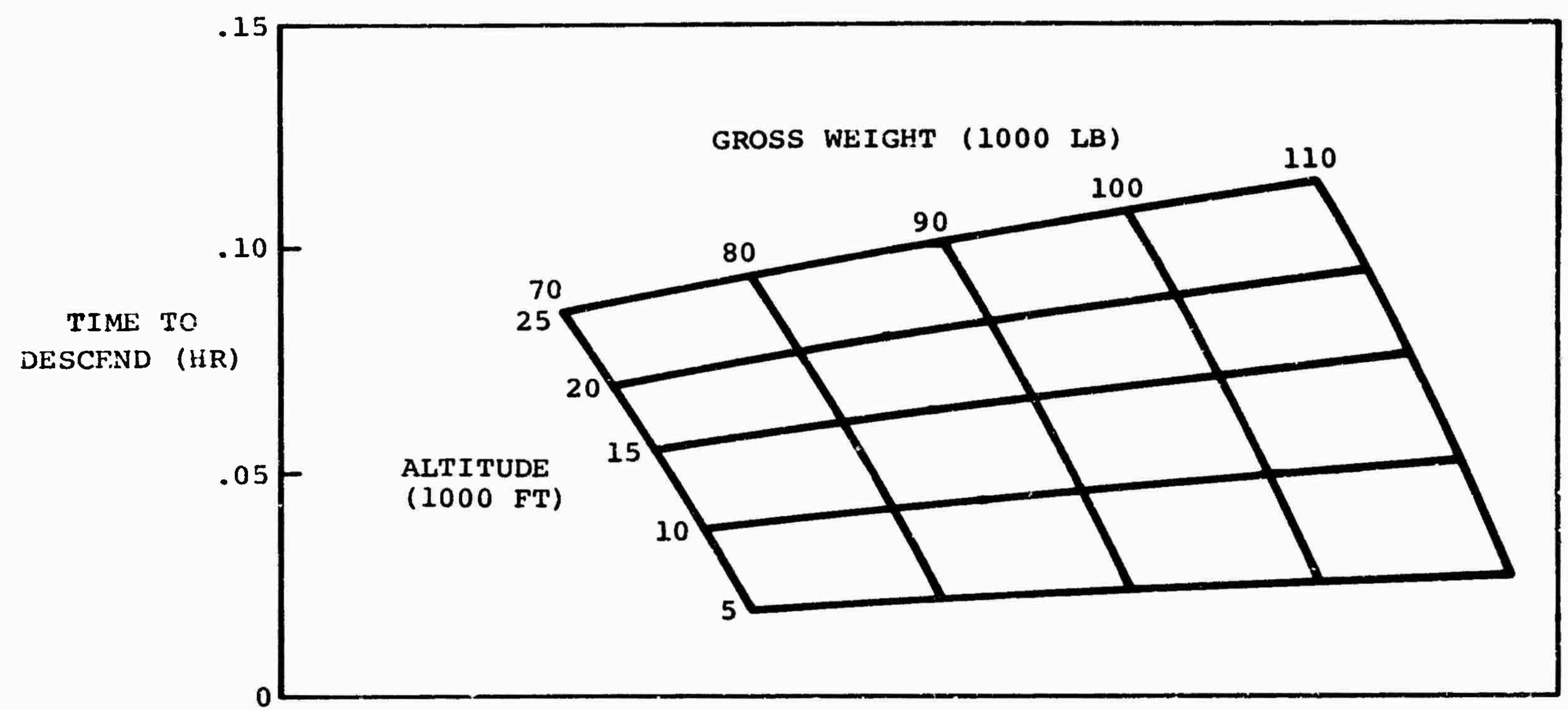


Figure 228. Design Point IV Time to Descend to Sea Level at Maximum Rate of Descent for Air Force Hot Day With All Engines Operating at Flight Idle Power.

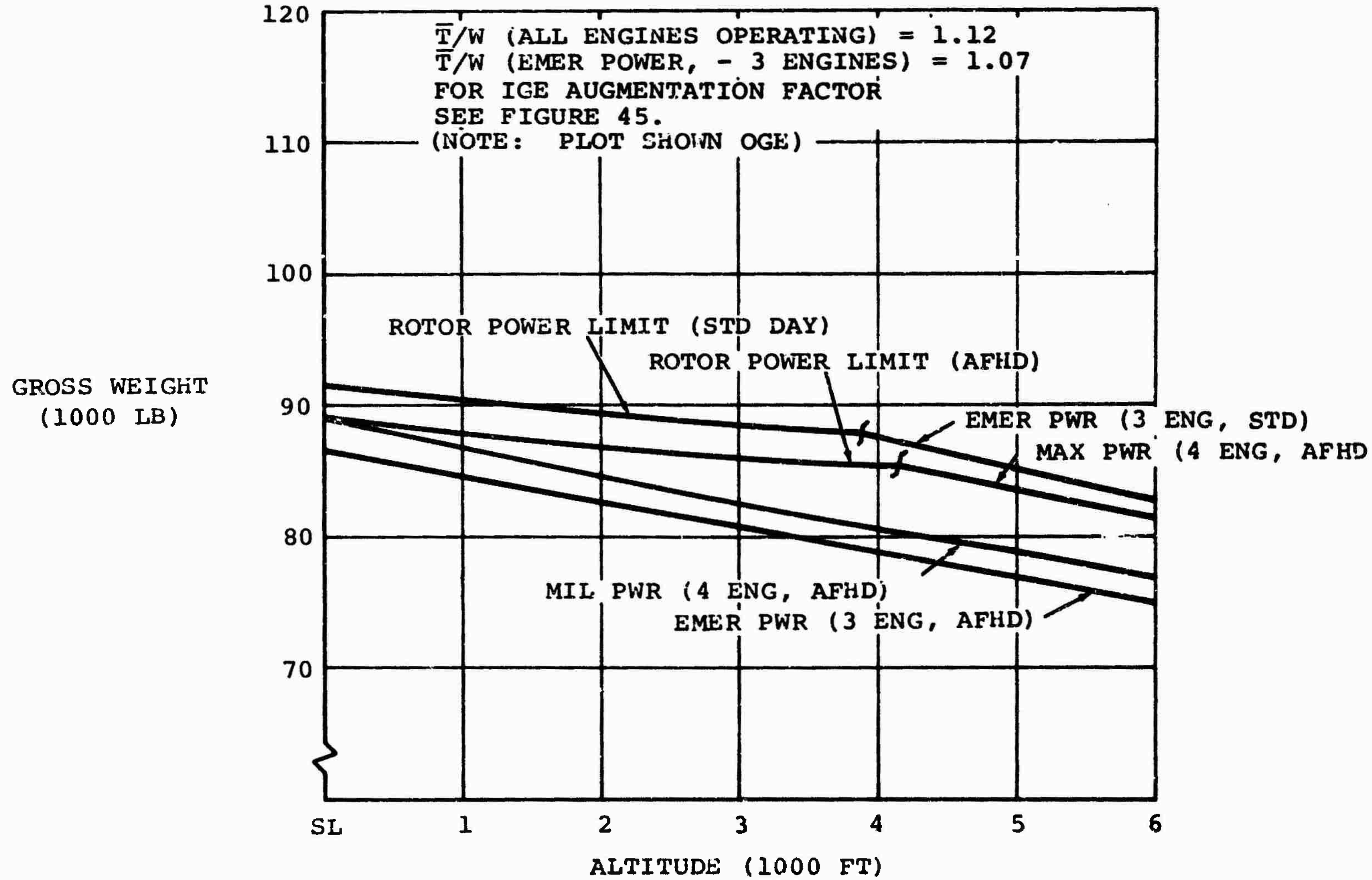


Figure 229. Design Point IV Gross Weight Hover Capability Versus Altitude for Standard Day and Air Force Hot Day Conditions.

APPENDIX II

MILITARY SPECIFICATION REVIEW

1. SUMMARY

A review of applicable military specifications has been performed to determine how these specifications apply to the folding-tilt-rotor aircraft. Generally, the available specifications are found to be adequate and only relatively minor interpretations or deviations are required. It has not been the purpose of this effort to devise these minor modifications, but rather to emphasize where these specifications are applicable and where deviations or changes are required. This review has emphasized the major structural, dynamics, and flying qualities specifications for airplanes and helicopters. Comments by specification and by paragraph of each specification are summarized.

2. INTRODUCTION

The folding-tilt-rotor vehicle is a composite, fixed/rotary-wing aircraft which is capable of flight in either the fixed wing or helicopter mode. Consequently, the composite vehicle must show compliance, where possible, with the appropriate military requirements currently specified for both fixed-wing and rotary-wing aircraft. The extent to which the various requirements of these two types of aircraft are applied to the vehicle will be largely dependent upon the vehicle mission requirements and configuration. The folding-tilt-rotor aircraft will operate in five modes of flight:

a. Hover or helicopter mode (speeds less than 35 knots).
b. Transition mode.
c. Tilt rotor airplane mode.
d. Conversion mode (the rotor stopping and folding process).
e. Airplane with stowed rotors mode.

It is anticipated that the design requirements for this type of vehicle will be in general accord with those specifications which are most appropriate for the means of lift used in the various flight modes. With rotor lift, the helicopter specifications should apply. For the transition mode, where lift is shared between the rotor system and the wing, the aircraft starts as a compound (winged) helicopter and approaches the end of transition as an airplane with upward inclined propellers. For the conversion mode, the rotor stopping and spin-up are

similar to the feathering cycle of propellers. Blade folding is essentially the same function as wing sweep changes of a variable sweep airplane. With this approach, the existing specifications are generally applicable, with minor exceptions.

3. FLYING QUALITIES CRITERIA

It is proposed that MIL-F-008785A (USAF) and the USAF-Cornell Aeronautical Laboratories (CAL) proposed V/STOL flying qualities specification be used for the folding-tilt-rotor aircraft at speeds above V_{con} and up to and including V_{con} respectively. For this purpose, it is proposed that V_{con} be defined as that airspeed at which a load factor of 1.2 can be achieved in the tilt-rotor airplane mode (rotor nacelles down and locked). The USAF-CAL proposed specification is superior to the existing helicopter flying qualities MIL-H-8501A and has the advantage of providing a consistent interface with the airplane flying qualities specification. MIL-H-8501A is also reviewed since it retains some miscellaneous helicopter requirements which are of value.

During conversions, the folding of the blades and the feathering and spin-up of the large rotors must be accomplished without compromising the flying qualities required in MIL-F-008785A (USAF). The section of this specification applicable is believed to be 3.5.6., Transfer to Alternate Control Modes, since this process is an intentional engagement or disengagement of a portion of the primary control system by the pilot. This specification requires that transient motions not exceed the following limits:

a. $\pm$ 0.05g normal or lateral acceleration at the pilot's station, and
b. $\pm$ 1 degree per second roll

It is assumed that conversion will only be attempted within the operational flight envelope (limited to the speed not to exceed V_{con} + 50 knots) and only with the airplane in its normal state.

Since spinning up or stopping of the rotors will cause longitudinal force transients, a criteria must be established for the transient effects. These criteria could be expressed in terms of maximum longitudinal acceleration and maximum allowable speed change. Pending thorough analysis, 0.25g and 10 knots respectively are tentatively suggested.

3.1 REVIEW OF MILITARY SPECIFICATION MIL-H-8501A, APRIL 1962, HELICOPTER FLYING AND GROUND HANDLING QUALITIES

It is recommended that this specification be replaced by the more recent USAF-CAL proposed VTOL flying qualities specifications for the stability and control aspects, retaining only those portions which are unique. Paragraphs are noted below as: (A) applicable, (D) to be deleted, or with comments. When applicable, these paragraphs only apply in the helicopter mode.

Paragraph	Comments
1.	
1.1	See above.
2.	A
3.	A
3.1	A
3.1.1	D. Limitations on requirements are needed.
3.1.2	A
3.2	Delete entire section.
3.3	Delete entire section.
3.4	Delete entire section.
3.5	A
3.5.1	A
3.5.2	A
3.5.3	A
3.5.4	A
3.5.4.1	A
3.5.4.2	A
3.5.4.3	A
3.5.4.4	A
3.5.4.5	A
3.5.5	Power-off autorotation will only be used in a multiple engine failure, upon depletion of all fuel and reserves or equivalent unusual emergency.
3.5.5.1	A
3.5.6	A. Interpreted to mean no unusual control forces.
3.5.7	A. Except that it will not be required that landings must be made at 15 knots or less.
3.5.8	D. Redundant.
3.5.9	D. Redundant.
3.6	Delete entire section.
3.7	A
3.7.1	A
3.7.2	A
3.7.3	A. Limit cycle oscillations which increase rotor or airframe stresses but do not significantly affect flying qualities will be allowed within the service flight envelope but not within the operational flight envelope. (Flight envelopes as defined in MIL-F-008785A.)

3.2 REVIEW OF PROPOSED MILITARY SPECIFICATION FOR VTOL AIRCRAFT BY CAL, OCTOBER 1968, FLYING QUALITIES OF PILOTED AIRCRAFT (AT SPEEDS LESS THAN V_{CON})

This proposed specification is recommended to be applicable in the helicopter mode and the tilt-rotor-transition mode. It is suggested that V_{con} be defined as the speed at which a load factor of 1.2 can be achieved in steady level flight with the flaps fully retracted and with the nacelles locked at the incidence for tilt-rotor-airplane mode operations. Paragraphs of this specification are applicable (A) if noted; comments are made as appropriate.

Paragraph	Comments
1.	A
1.1	See definition of V_{con} given above.
1.2	A
1.3	A
2.	A
2.1	A
2.2	A
3.	A
3.1	A
3.1.1	A
3.1.2	A
3.1.3	Weights. Effects of nacelle tilting must be included in the calculations of center-of-gravity.
3.1.4	A
3.1.5	A
3.1.6	A
3.1.7	A
3.1.8	A
3.1.9	A
3.1.10	A
3.1.11	A
3.1.12	A
3.1.13	A
3.1.14	A
3.1.15	A
3.2	A
3.2.1	A
3.2.2	A
3.2.2.1	A
3.2.2.1a	Oscillatory Mode. The requirement that all oscillatory modes be damped for Level 3 flight is excessively restrictive. Neutral stability would be more appropriate.
3.2.2.1b	A
3.2.2.2	A
3.2.3	A

Paragraph	Comments
3.2.4	A
3.2.5	A
3.2.6	A
3.2.7	A
3.2.7.1	A
3.2.7.2	A
3.2.7.3	A
3.2.7.4	A
3.2.7.5	A
3.3	A
3.3.1	A
3.3.2	A
3.3.3	A
3.3.4	A
3.3.5	A
3.3.6	A
3.3.7	A
3.3.7.1	Maneuvering Control Margins. With a hard-over failure of the stabilizing system enough control should remain that the Level 3 requirements of Table I can be achieved.
3.3.7.2	A
3.3.8	A
3.3.9	A
3.3.10	A
3.3.11	A
3.3.12	A
3.3.13	A
3.3.14	A
3.3.14.1	A
3.3.14.2	A
3.3.14.3	A
3.3.14.4	A
3.3.15	A
3.3.16	A
3.3.16.1	A
3.3.16.2	A
3.3.16.3	A
3.3.16.4	Rudder-Pedal Induced Rolls. Coupling of directional controls so that yaw inputs cause the required roll values would need to be a function of airspeed. It is recommended that there be no coupling up to 35 knots equivalent airspeed and then this coupling should increase with the dynamic pressure reaching the value specified at about V_{con}.
3.3.16.5	A
3.3.17	A
3.3.17.1	A
3.3.17.2	A

Paragraph	Comments
3.3.17.3	A
3.3.18	A
3.3.18.1	A
3.3.18.2	A
3.3.18.3	A
3.3.19	A
3.3.20	Lateral-Directional Control with Asymmetric Thrust. Not applicable; rotors are interconnected.
3.4	A
3.4.1	A
3.4.2	A
3.4.3	A
3.4.4	A
3.4.5	A
3.4.6	A
3.4.7	A
3.4.8	Control of Thrust Vector Rotation. Automatic thrust vectoring is anticipated to be used for this aircraft. This specification should not preclude use of such a system.
3.4.9	A
3.5	A
3.5.1	A
3.5.2	A
3.5.3	A
3.5.4	A
3.5.5	A
3.5.6	A
3.5.7	A
3.5.8	A
3.6	A
3.6.1	A
3.6.2	A
3.6.3	A
3.6.4	A
3.6.5	A
3.6.6	A
3.6.7	A
3.6.8	A
3.6.9	A
4.	A
4.1	A
5.	A
5.1	A

3.3 REVIEW OF MIL-F-008785A (USAF), 31 OCTOBER 1968, FLYING QUALITIES OF PILOTED AIRPLANES

This specification is generally applicable only in the tilt-rotor airplane and the airplane with rotor stowed modes of flight. Paragraphs of this specification are applicable (A) if noted; comments are made as appropriate.

Paragraph	Comments
1.1	A
1.2	A
1.3	A
1.4	A
1.5	A
2.1	A
3.1.1	A
3.1.2	A
3.1.3	A
3.1.4	A
3.1.5	A
3.1.6	A
3.1.7	A
3.1.8.1	A
3.1.8.2	Minimum Service Speed. Only applicable for take-off and landings with rotors stowed. This is not considered a normal operating condition.
3.1.8.3	A
3.1.8.4	A
3.1.9	A
3.1.9.1	Maximum Permissible Speed. Limit (structural) speeds are also established for the helicopter mode (nacelles locked at 90-degree incidence), transition mode (nacelles not locked at 0-degree incidence) and in the tilt-rotor airplane mode (rotors not stowed).
3.1.10	A
3.2.1	A
3.2.1.1	A
3.2.1.2	A
3.2.1.3	Flight-Path Stability. Only applicable for stowed rotor operations. In the VTOL transition mode, the pilot will actuate the thrust lever which will indirectly actuate the throttles. The VTOL criteria shall apply in this mode.
3.2.2	A
3.2.2.1	A
3.2.2.2	A
3.2.2.3	A
3.2.3	A
3.2.3.1	A

Paragraph	Comments
3.2.3.2	A
3.2.3.3	Longitudinal Control in Takeoff. Only applicable for stowed rotor operations.
3.2.3.4	Longitudinal Control in Landing. Only applicable for stowed rotor operations.
3.2.3.5	A
3.2.3.6	A
3.2.3.7	A
3.3	A
3.3.1	A
3.3.1.1	A
3.3.1.2	A
3.3.1.3	A
3.3.1.4	A
3.3.2.1	A
3.3.2.2	A
3.3.2.3	A
3.3.2.4	A
3.3.2.5	A
3.3.2.6	Turn Coordination. Turns will not necessarily be coordinated in VTOL modes.
3.3.3	A
3.3.4.1	A
3.3.4.2	A
3.3.4.3	A
3.3.4.4	A
3.3.4.5	A
3.3.5	A
3.3.5.1	A
3.3.5.2	A
3.3.6	A
3.3.6.1	A
3.3.6.2	A
3.3.6.3	A
3.3.7	Lateral-Directional Control in Cross Winds. Take-off and landing with the rotors stowed is not considered normal operation. Compromises for cross wind operations should be as required for Level 3 flying qualities.
3.3.7.1	
3.3.7.2	
3.3.7.3	A
3.3.8	A
3.3.9	A
3.3.9.1	Thrust Loss. Takeoffs will normally be made in the VTOL or STOL modes; rotors are interconnected.
3.3.9.2	
3.3.9.3	A
3.3.9.4	A
3.3.9.5	A
3.4	A
3.4.1	A

Paragraph	Comments
3.4.2	A
3.4.3	A
3.4.4	A
3.4.5	A
3.4.6	A
3.4.7	A
3.4.8	A
3.4.9	A
3.4.10	A
3.5	A
3.5.1	A
3.5.2	A
3.5.2.1	A
3.5.2.2	A
3.5.2.3	A
3.5.2.4	A
3.5.3	A
3.5.4	A
3.5.5	A
3.5.5.1	A
3.5.5.2	A
3.5.6	Transfer to Alternate Control Modes. The conversion process is considered as a transfer to an alternate control mode as thrust control is transferred from the rotors to the fan jets.
3.5.6.1	A
3.5.6.2	A
3.6	A
3.6.1	A
3.6.2	A
3.6.3	A
3.6.4	A
3.6.5	Direct Normal Force Control. Flight in the tilt-rotor airplane mode will be controlled by a mix of rotor and airplane control actuations. In general, the rotor forces will be considered as "direct normal forces".
3.7	A
3.7.1	A
3.7.2	A
3.7.3	A
3.7.4	A
3.7.5	A
4.	A
4.1	A
4.2	A
4.3	A
4.4	A
5.	A
5.1	A

4. STRUCTURAL CRITERIA

The pertinent structural specification for the helicopter mode is MIL-S-8698 (ASG), Structural Design Requirements, Helicopters. The pertinent structural specifications for the fixed wing modes are:

a. MIL-A-8860 (ASG), Airplane Strength and Rigidity, General Specification for.
b. MIL-A-8861 (ASG), Airplane Strength and Rigidity Flight Loads.
c. MIL-A-8862 (ASG), Airplane Strength and Rigidity Landplane Landing and Ground Handling Loads.
d. MIL-A-8865 (ASG), Airplane Strength and Rigidity Miscellaneous Loads.
e. MIL-A-8866 (ASG), Airplane Strength and Rigidity Reliability Requirements, Repeated Loads, and Fatigue.
f. MIL-A-8870 (ASG), Airplane Strength and Rigidity Vibration, Flutter and Divergence.

The rotary-wing vehicle category selected from MIL-S-8698 (ASG) is a class III helicopter. The fixed-wing vehicle category selected from MIL-A-8861 (ASG) is USAF CLASS $C_{ASSAULT}$. Each of the specifications listed above is reviewed in the following sections.

4.1 REVIEW OF MIL-A-8860 (ASG), AIRPLANE STRENGTH AND RIGIDITY GENERAL SPECIFICATION FOR

This specification is generally applicable to the tilt-rotor and the stowed rotor fixed wing airplane modes. Paragraphs of this specification are applicable (A) if noted; comments are made as appropriate.

Paragraph	Comments
1.	A
2.	A
3.	A
4.	A
5.	A
6.1	A
6.2	A
6.2.1	A
6.2.1.1	Basic (A). (Add) The vehicle shall be in the tilt-rotor and the stowed rotor fixed wing airplane modes.
6.2.1.2	A
6.2.1.3	A

Paragraph	Comments
6.2.1.4	Landing Approach. Landing is applicable to the transition mode. Landing in the stowed-rotor fixed-wing airplane mode configuration is not considered a normal operation.
6.2.1.5	Takeoff is applicable to the transition mode. Takeoff in the fixed-wing airplane mode with rotors stowed is not considered a normal operation.
6.2.2	A
6.2.2.1	A
6.2.2.2	A
6.2.2.3	A
6.2.2.4	A
6.2.2.5	Carrier Landing Design Gross Weight. Not applicable.
6.2.2.6	A
6.2.2.7	A
6.2.2.8	A
6.2.3	A
6.2.3.1	A
6.2.3.2	A
6.2.3.3	A
6.2.3.4	A
6.2.3.5	Catipult End Air Speed (V_C). Not applicable.
6.2.3.6	Maximum Engaging Speed (V_E). Not applicable.
6.2.3.7	A
6.2.3.8	A
6.2.3.9	A
6.2.3.10	Minimum Approach Speed $(V_{PA})_{min}$. Not applicable.
6.2.3.11	A
6.2.3.12	Stalling Speed with Power (V_{SPA}). Not applicable.
6.2.3.13	A
	Transition Speed (V_{CON}). The forward speed at which the vehicle is fully converted from the transition mode to the tilt-rotor mode.
	Tilt-Rotor Limit Speed. Maximum speed for operation in the tilt-rotor fixed wing airplane mode.
	Minimum Stowing Speed. Minimum speed for stowing and unfolding the rotor.
	Maximum Stowing Speed. Maximum speed for stowing and unfolding the rotor.
6.2.4	A
6.2.5	A
6.3	A

4.2 REVIEW OF MIL-A-8861 (ASG), AIRPLANE STRENGTH AND RIGIDITY FLIGHT LOADS

This specification is generally applicable to the tilt rotor and the stowed rotor fixed wing airplane modes. Paragraphs of this specification are applicable (A) if noted; comments are made as appropriate.

Paragraph	Comments
1.	A
2.	A
3.1	A
3.1.1	A
3.1.2	A
3.1.3	A
3.1.3.1	A
3.1.4	A
3.1.5	A
3.1.6	A
3.1.7	A
3.1.8	A
3.1.9	A
3.1.10	A
3.1.11	A
3.1.12	A
3.1.13	A
3.1.14	A
3.1.15	A
	Rotor Loads. Loads on the rotor and nacelle, and wing reaction loads, shall be those resulting from the loading conditions of this specification for the tilt-rotor-fixed-wing airplane mode and the transition mode.
3.2.1	A
3.2.2	A
3.2.2.1	A
3.2.2.2	A
3.2.3	Applicable for transition mode.
3.3.1	A
3.3.1.1	A
3.3.1.2	Not applicable.
3.3.2	Applicable for transition mode.
3.3.3	A
3.3.3.1	A
3.3.3.2	A
3.3.3.3	A
3.3.3.4	Applicable for transition mode.
3.3.3.5	A
3.3.3.6	Not applicable.
3.3.3.7	A

Paragraph	Comments
3.4	Not applicable.
3.5	A
3.5.1	A
3.5.2	A
3.5.3	Not applicable.
3.5.4	Not applicable.
3.6	A
4.	A
5.	A
6.	A

4.3 REVIEW OF MIL-A-8862 (ASG), AIRPLANE STRENGTH AND RIGIDITY LANDPLANE LANDING AND GROUND HANDLING LOADS

Landing of the folding tilt rotor will normally be made in the helicopter or transition mode. Landing in the stowed rotor fixed airplane mode will not be considered normal operation. Landing conditions are covered by MIL-S-8698 (ASG), Structural Design Requirements, Helicopters. The ground handling conditions described in this specification are similar to those given in the above reference helicopter specification. Paragraphs of this specification are applicable (A) if noted; comments are made as appropriate.

Paragraph	Comments
1.	A
2.	A
3.1	A
3.1.1	A
3.1.2	A
3.1.3	A
3.1.4	A
3.1.5	A
3.2	A
3.3	Taxiing (A).
3.3.1	A
3.3.1.1	A
3.3.1.2	A
3.3.1.3	A
3.3.1.4	A
3.3.1.5	A
3.3.2	A
3.3.3	A
3.3.4	A
3.3.5	A
3.3.6	A
3.4.1	A
3.4.2	A

Paragraph	Comments
3.4.3	A
3.4.4	Not applicable. See MIL-S-8698 (ASG).
3.5.1	A
3.5.2	A
3.5.3	A
3.5.4	A
3.5.4.1	A
3.5.4.2	A
3.5.4.3	A
3.5.4.4	A
3.5.5	A
3.5.6	A
3.6	A
4.	A
5.	A
6.	A

4.4 REVIEW OF MIL-A-8865, AIRPLANE STRENGTH AND RIGIDITY MISCELLANEOUS LOADS

Paragraphs of this specification are applicable (A) if noted; comments are made as appropriate.

Paragraph	Comments
1.	A
2.	A
3.1	A
3.2	A
3.2.1	A
3.2.2	A
3.2.3	A
3.3.1	A
3.3.2	A
3.3.3	A
3.4	Not applicable.
3.5	A
3.5.1	Not applicable.
3.6	A
3.7	A
3.7.1	A
3.7.2	A
3.7.3	A
3.7.4	A
3.8	A
3.9	A
3.10	A
3.11	Not applicable.

Paragraph	Comments
4.	A
5.	A
6.	A

4.5 REVIEW OF MIL-A-8866 (ASG), AIRPLANE STRENGTH AND RIGIDITY RELIABILITY REQUIREMENTS, REPEATED LOADS AND FATIGUE

This specification is generally applicable to the vehicle airframe structure. Paragraphs are applicable (A) if noted; comments are made as appropriate.

Paragraph	Comments
1.	A
2.	A
3.1	A
3.2	A
3.3	A
3.4	A
3.5	Sinking Speeds. The paragraph is generally applicable. The referenced Table IV required modification to agree with vehicle usage.
3.5.1	Not applicable.
3.6	The paragraph is generally applicable. The referenced Table IV required modification to agree with vehicle usage.
3.7	Not applicable.
3.8	A
3.9	A
3.10	A
3.11	A
3.12	A
3.13	Not applicable.
3.14	Not applicable. Rotor Loads. Particular attention shall be given to the loads on the nacelle and wing from the rotor.
4.	A
5.	A
6.	A

4.6 <u>REVIEW OF MIL-S-8698 (ASG), STRUCTURAL DESIGN REQUIREMENTS, HELICOPTERS</u>

This specification is generally applicable to the helicopter or hover mode and the transition mode. Paragraphs are applicable (A) if noted; comments are made as appropriate.

Paragraph	Comments
1.1	A
1.2	A
1.3	Definition of classes for this type of vehicle is required.
2.1	A
2.2	A
3.1.1	A
3.1.1.1	A
3.1.1.2	A
3.1.2.1	A
3.1.2.2	A
3.1.3.1	A
3.1.3.2	A
3.1.3.3	A
3.1.3.4	A
3.1.4	A
3.1.5	A
3.1.5.1	A
3.1.5.2	A
3.1.6	A
3.1.7	A
3.1.8	A
3.1.9	This paragraph is applicable but subject required further discussion.
3.1.10	A
3.2.1.1	A
3.2.1.2	A
3.2.1.3	A
3.2.2.1	Not applicable.
3.2.2.2	A
3.2.2.3	Forward speed shall be the critical speed.
3.2.2.4	A
3.2.3.1	Forward speed shall be the critical speed.
3.2.3.2	Forward speed shall be the critical speed.
3.2.4.1	Forward speed shall be the critical speed.
3.2.4.2	Forward speed shall be the critical speed.
3.2.5	Forward speed shall be the critical speed.
3.3.1	A
3.3.2	A
3.3.3	A
3.4.1	A
3.4.1.1	A
3.4.2	A

Paragraph	Comments
3.4.3	A
3.4.4	A
3.4.5	A
3.4.5.1	A
3.4.5.2	A
3.4.5.3	A
3.4.5.4	A
3.4.6	A
3.4.6.1	A
3.4.6.2	A
3.4.6.3	A
3.4.7	A
3.5	A
3.6.1	A
3.6.2	The intent of this paragraph is applicable since the rotor blade flutter criteria is for flap-pitch coupled flutter. A new criteria is required for stall flutter.
3.6.3	A
3.6.3.1	A
3.6.3.2	A
3.6.3.3	A
3.6.3.3.1	A
3.6.4	This paragraph is applicable but shall not preclude the use of supercritical shafts.
3.6.5.1	A
3.6.5.2	Not applicable.
3.6.5.2.1	A
3.6.5.2.2	A
3.6.5.2.3	A
3.6.5.2.4	A
3.6.5.3	A
3.6.6	A
3.6.6.1	A
3.7	A
4.	A
5.	A
6.	A

4.7 REVIEW OF MILITARY SPECIFICATION MIL-A-8870 (ASG), MAY 1960, AIRPLANE STRENGTH AND RIGIDITY - VIBRATION, FLUTTER, AND DIVERGENCE

This specification is generally applicable for all modes of flight. Paragraphs are applicable (A) if noted; comments are made as deemed appropriate.

Paragraph	Comments
1	A
1.1	A
1.2	A
1.3	Deviations. Some deviations are required and are noted below.
2.	A
2.1	A
3.	A
3.1	General. (Add) rotor blade or rotor coupled limit cycle oscillations which increase rotor or airframe stresses but do not significantly affect flying qualities (e.g., stall flutter) will be allowed within the service flight envelope but not within the operational flight envelope. (See flight envelope definition in MIL-F-008785A.) Proof that these oscillations will remain limit cycle and will not diverge is required.
3.1.2	A
3.1.3	A
3.2	A
3.2.1	A
3.2.1.1	A
3.2.1.2	A
3.2.1.3	A
3.2.1.4	A
3.2.2	A
3.2.2.1	A
3.2.2.2	A
3.2.2.3	A
3.2.2.4	A
3.2.3	A
3.2.3.1	A
3.2.3.2	A
3.2.4	A
3.2.4.1	A
3.2.4.2	A
3.2.4.3	A
3.2.4.4	A
3.2.5	A
3.2.6	A
3.2.7	A
3.2.8	A

Paragraph	Comments
3.2.9	A
3.2.10	A
3.2.11	A
3.2.12	Antivibration Systems. Requirements for rotor whirl flutter stability may be in conflict with this requirement.
3.3	A
3.3.1	A
3.3.1.1	A
3.3.1.2	A
3.3.2	Applicable in its entirety.
3.3.3	Applicable in its entirety.
3.3.4	A
3.3.5	A
3.3.6	A
3.3.6.1	A
3.3.6.2	A
3.3.7	Not expected to be applicable for anticipated missions.
3.3.8	A
3.3.9	A
3.3.10	A
3.3.11	A
3.3.12	A
4.	A
4.1	A
4.2	A
4.3	A
4.4	A
4.5	A
4.6	A
4.7	Not expected to be applicable for anticipated missions.
4.8	A
4.9	A
4.9.1	A
4.9.1.1	A
4.9.1.2	A
4.9.1.2.1	Not applicable.
4.9.1.2.2	A
4.9.1.2.3	A
4.9.1.2.4	A
4.9.1.2.5	A
4.9.1.2.6	A
4.9.1.2.7	A
4.9.1.2.8	A
4.9.1.3	A
4.9.2	A
4.10	A
4.11	A
5.	A